Evaluation of the Proengin AP4C Detector Against Selected Chemical Vapors

Contract #: NMA401-02-9-2002

Final Technical Report

30 June 2009

Disclaimer: This data has not been reviewed or checked for accuracy and should not be relied upon or cited.

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Acronyms used in this document

AC	Hydrogen Cyanide
AEGL	Acute Exposure Guideline Levels
Cl_2	Chlorine
CK	Cyanogen Chloride
CWA	Chemical Warfare Agent
DEAE	N,N-Diethylaminoethanol
EPA	U.S. Environmental Protection Agency
GB	Sarin
GC/MS	Gas Chromatography/Mass Spectrometry
HD	Distilled Mustard (Sulfur Mustard)
IDLH	Immediately Dangerous to Life and Health
L	Lewisite
LPM	Liter(s) per Minute
MINICAMS®	Miniature Chemical Agent Monitoring System
NIST	National Institute of Standards and Technology
ORD	Office of Research and Development
PEL	Permissible Exposure Limit
RH	Relative Humidity
SA	Arsine
TIC	Toxic Industrial Chemical

EXECUTIVE SUMMARY

CUBRC is pleased to provide this final technical report to the Environmental Protection Agency (EPA) as part of its evaluation of the performance of the AP4C detector manufactured by Proengin. The objective of this testing is to evaluate the instrument performance against a set of operational parameters provided by the EPA. The performance parameters include response time, response threshold, repeatability, recovery time, temperature and relative humidity effects, interferent effects, cold and hot start, and battery operation. The tests were carried out with a set of toxic industrial chemicals (TICs) consisting of hydrogen cyanide (AC), cyanogens chloride (CK), chlorine (Cl_2) and arsine (SA) and chemical warfare agents (CWAs) consisting of VX, sarin (GB), sulfur mustard (HD), and lewisiste (L), Additionally the AP4C was evaluated against the following interferents: paint fumes (vapors), ammonia cleaner, air freshener, gasoline engine exhaust, and N,N-Diethylethanolamine (DEAE) either singularly or combined with CWAs or TICs. The test matrix contained multiple exposures of the selected chemicals at Immediately Dangerous to Life and Health (IDLH) levels and Permissible Exposure Levels (PEL) at a variety of environmental conditions (temperature and relative humidity).

The following report discusses the technical approach, facilities, and equipment used to perform these experiments, and provides detailed information on the experimental test parameters applied during each experiment.

1. INTRODUCTION

The US EPA/ORD (Office of Research and Development) developed a program to evaluate the performance of selected commercial chemical detection systems. The Proengin AP4C was selected by the EPA for evaluation in this program. The AP4C is a portable chemical contamination control device used to directly detect chemical agents in the form of vapor, aerosols, aerosols, dust and, with the S4PE attachment (not tested), in the form of liquid. The detector uses flame spectrometry technology. The AP4C detects compounds of phosphorus (such as all G and V agents: GA, GB, GD, GE, GF, VE, VX), compounds of sulfur (such as H, HD, HL agents, Arsenic compounds (contained in L, SA, DM) and other gases such as Ammonia, Cyanogen Chloride, Hydrogen Cyanide, etc.

CUBRC provided laboratory testing involving the chemical warfare agents (CWAs) Sarin (GB), Sulfur Mustard (HD), VX, and Lewisite (L) and toxic industrial chemicals (TICs) Cyanogen Chloride (CK), Hydrogen Cyanide (AC), Chlorine (Cl_2) and Arsine (SA). Additionally the AP4C was evaluated against the following interferents: paint vapors, ammonia cleaner, air freshener, gasoline engine exhaust, and DEAE either singularly or combined with CWAs or TICs.

2. OBJECTIVES AND TECHNICAL APPROACH

2.1. Objectives

The purpose of this testing was to evaluate the performance and characteristics of the Proengin AP4C against the manufacturers' stated specifications.

2.2 Technical Approach

The testing was conducted in accordance with the *Test/QA Plan For Evaluation of Chemical Threat Analyzers* (February 2009; Appendix B) which was based on the EPA supplied Test / Quality Assurance Plan entitled "*Verification of Portable Ion Mobility Spectrometers for Detection of Chemicals and Chemical Agents in Buildings"*. The detector was evaluated for cold and hot start-ups, battery life, response and recovery times, detection limits, and interferent responses.

2.3 Chemical Test Compounds

The TICs used in testing were:

- Hydrogen cyanide (AC)
- Cyanogen Chloride (CK)
- Chlorine (Cl_2)
- Arsine (SA)

The Chemical Warfare Agents (CWA) were:

- Sarin (GB)
- Sulfur Mustard (HD)
- VX
- Lewisite (L)

Table 1 summarizes the concentrations of each TIC and CWA used in this detector evaluation.

Table 1 – Target TIC and CWA Challenge Concentrations

TIC/CWA	IDLH [mg/m^3]	PEL [mg/m^3]
Cyanogen Chloride (CK)	50.0	0.60
Hydrogen Cyanide (AC)	55.3	11.1
Arsine (SA)	9.56	0.20
Chlorine ($Cl_{2)}$	29.0	N/A
VX	0.02	1.0×10^{-5}
Sarin (GB)	0.10	3.0×10^{-5}
Mustard (HD)	0.70	0.003*
Lewisite (L)	0.23**	0.003
*There is no PEL for HD. This value is the AEGL for HD. **There is no IDLH level available for L. The value stated is the AEGL 2 value at 30 min.		

3. TEST MATRIX

The AP4C test matrix contained multiple exposures of selected chemicals at Immediately Dangerous to Life and Health (IDLH) levels and Permissible Exposure Levels (PEL) at a variety of environmental conditions. The complete test program evaluated multiple aspects of the AP4C as briefly described below:

Response and Recovery Time: This portion of the program characterized how rapidly the detector alarmed and cleared down in the presence and subsequent absence of a chemical vapor challenge. The time for the detector to reach alarm status from a baseline (non-alarm) status after the initiation of a chemical challenge was recorded as the response time. The time required for the detector to clear back down to baseline (non-alarm) status upon removal of the chemical challenge was recorded as the recovery time. Table 2 below lists the chemicals and conditions tested in this portion of the program.

Table 2 – Response and Recovery Time Challenges

TIC/CWA	Concentration	Temp (°C)	RH (%)	Total Data Points
CK	IDLH	22	50	5
CK	PEL	22	50	5
CK	IDLH	22	20	5
CK	IDLH	22	50	5
CK	IDLH	22	80	5
CK	IDLH	5	50	5
CK	IDLH	35	50	5
CK	IDLH	35	80	5
AC	IDLH	22	50	5
AC	PEL	22	50	5
AC	IDLH	22	20	5
AC	IDLH	22	50	5
AC	IDLH	22	80	5
AC	IDLH	5	50	5
AC	IDLH	35	50	5
AC	IDLH	35	80	5
SA	IDLH	22	50	5
SA	PEL	22	50	5
SA	IDLH	22	20	5
SA	IDLH	22	50	5
SA	IDLH	22	80	5
SA	IDLH	5	50	5
SA	IDLH	35	50	5
SA	IDLH	35	80	5
Cl_2	IDLH	22	50	1
GB	IDLH	22	50	5
GB	PEL	22	50	5
GB	IDLH	22	20	5
GB	IDLH	22	50	5
GB	IDLH	22	80	5
GB	IDLH	5	50	5
GB	IDLH	35	50	5
GB	IDLH	35	80	5
HD	IDLH	22	50	5
HD	PEL	22	50	5
HD	IDLH	22	20	5
HD	IDLH	22	50	5

Table 2 (con't)

TIC/CWA	Concentration	Temp (°C)	RH (%)	Total Data Points
HD	IDLH	22	80	5
HD	IDLH	35	50	5
HD	IDLH	35	80	5
VX	IDLH	22	50	5
VX	PEL	22	50	5
VX	IDLH	22	20	5
VX	IDLH	22	50	5
VX	IDLH	22	80	5
VX	IDLH	5	50	5
VX	IDLH	35	50	5
VX	IDLH	35	80	5

Response Threshold (Lowest Detection Limit): This portion of the program characterized the lowest concentration of chemical vapor that would result in a detector response within a 5 minute challenge. This differed from the preceding experiments in that here the detector was presented with a chemical vapor challenge at the stated detection limit of the detector for that chemical (disregarding IDLH or PEL value for the specific chemical). If the detector responded at this level, it was challenged with successively lower concentrations until no response was reported. If the detector did not respond at the initial level, the challenge concentration was increased until a response was elicited. Table 3 below lists the concentration ranges used for each chemical in this portion of the test program.

Table 3 – Response Threshold Challenges

TIC/CWA	Concentration Range mg/m^3	Temp (°C)	RH (%)	Total Data Points
CK	10 – 30	22	50	4
AC	5 – 10	22	50	2
SA	0.025 - 0.2	22	50	4
GB	0.005 – 0.01	22	50	2
HD	0.39 – 0.58	22	50	3
VX	0.006 – 0.009	22	50	2
L	1.19 – 3.35	22	50	6

Interferent Effects: The detector was challenged with interferents (air freshener, ammonia, DEAE, engine exhaust, paint vapor) at 1% headspace concentration both in the presence and absence of chemical vapors. Response time, response, and recovery time were

measured in the presence of the interferents. Table 4 lists the interferents and conditions tested in this portion of the program.

Table 4 – Interferent Effect Challenges

TIC/CWA	Concentration	Temp (°C)	RH (%)	Total Data Points	Interferent
None	Air - Interferent	22	50	5	Paint Vapor
None	Air - Interferent	22	50	5	Ammonia
None	Air - Interferent	22	50	5	Air Freshener
None	Air - Interferent	22	50	5	DEAE
None	Air - Interferent	22	50	5	Engine Exhaust
CK	IDLH	22	50	5	Paint Vapor
CK	IDLH	22	50	5	Ammonia
CK	IDLH	22	50	5	Air Freshener
CK	IDLH	22	50	5	DEAE
CK	IDLH	22	50	5	Engine Exhaust
AC	IDLH	22	50	5	Paint Vapor
AC	IDLH	22	50	5	Ammonia
AC	IDLH	22	50	5	Air Freshener
AC	IDLH	22	50	5	DEAE
AC	IDLH	22	50	5	Engine Exhaust
SA	IDLH	22	50	5	Paint Vapor
SA	IDLH	22	50	5	Ammonia
SA	IDLH	22	50	5	Air Freshener
SA	IDLH	22	50	5	DEAE
SA	IDLH	22	50	5	Engine Exhaust
GB	IDLH	22	50	5	Paint Vapor
GB	IDLH	22	50	5	Ammonia
GB	IDLH	22	50	5	Air Freshener
GB	IDLH	22	50	5	DEAE
GB	IDLH	22	50	5	Engine Exhaust
HD	IDLH	22	50	5	Paint Vapor
HD	IDLH	22	50	5	Ammonia
HD	IDLH	22	50	5	Air Freshener
HD	IDLH	22	50	5	DEAE
HD	IDLH	22	50	5	Engine Exhaust
VX	IDLH	22	50	5	Paint Vapor
VX	IDLH	22	50	5	Ammonia
VX	IDLH	22	50	5	Air Freshener
VX	IDLH	22	50	5	DEAE
VX	IDLH	22	50	5	Engine Exhaust

Hot Start/Cold Start: Evaluated the performance of the AP4C after cold and hot storage; the start up and the time to reach "ready" status were determined. As a reference, the base time required for the detector to reach "ready" status from first being powered on at room

temperature was determined. Table 5 below outlines the conditions used to determine the startup times of the AP4C in this portion of the test program.

Table 5 – Hot Start/Cold Start Conditions

TIC	Concentration	Temp (°C)	RH (%)	Total Data Points	Test Type
CK	IDLH	22	50	5	Cold Start
CK	IDLH	5	50	5	Cold Start
CK	IDLH	40	50	5	Hot Start

Battery Life: Assess the performance of the detector and batteries under continuous operation. This test was consisted of 25 challenges of CK at 50 mg/m^3 over 14 hours as outlined in Table 6 below.

Table 6 – Battery Life Test Conditions

TIC	Concentration	Temp (°C)	RH (%)	Total Data Points	Test Type
CK	IDLH	22	50	25	Battery Life

Repeatability: Repeatability (%RSD) was assessed using data obtained from five consecuttive challenge/clean air cycles. The series of test results at the same environmental and concentration conditions were used to quantify the repeatability of the measurements and the effects of test conditions on repeatability.

Temperature and Humidity Effects: The effect that the temperature and humidity of the vapor stream has on the response of the AP4C was evaluated. In all cases the AP4C detector was maintained at the same temperature as the challenge air stream. The challenge air stream also was maintained at a specific relative humidity (RH). Table 7 below lists the environmental conditions used in throughout the entire test program.

Table 7. Temperature and Relative Humidity Conditions for Proengin AP4C Evaluation

RH(%)	Temperature (°C)		
	5±3°C	22±3°C	35±3°C
≤20	X[a]	X	X
50±5%	X	X	X
80±5%	X	X	X

[a]HD freezes at ~14°C so this condition will not be included

4. FACILITIES, EQUIPMENT, AND INSTRUMENTATION

4.1 Chemical Agent Test Facilities

All testing on this program was performed in certified chemical agent fume hoods located at CUBRC's chemical agent test facility located approximately 35 miles south of Buffalo, New York. Testing was conducted in May and June 2009. CUBRC, under a Bailment Contract with the U.S. Army RDECOM, is certified to receive, store, handle, and consume chemical warfare agents in support of Department of Defense programs.

4.2 Test System

CUBRC's chemical agent detector evaluation system consist of vapor generation equipment, vapor dilution systems, environmental control systems, temperature chambers, and associated analytical instrumentation. The systems have been specifically designed to rapidly toggle between clean air and vapor-laden challenges with no effect on other environmental test conditions (temperature, relative humidity, pressure, etc.). The system is capable of maintaining extremely stable challenge concentrations and environmental conditions (±5%). Flow rates in the range of 10 mL/min to >10 Liters per minute (LPM) can be provided to the agent detectors under evaluation. Flows involved in concentration accuracy were passed through NIST-Traceable calibrated flow controllers and flow meters. Elapsed time was monitored on a calibrated timer and all temperature and relative humidity measurements were obtained by a calibrated thermometer and hygrometer.

Figure 1 shown below is a schematic of the vapor generation and delivery system:

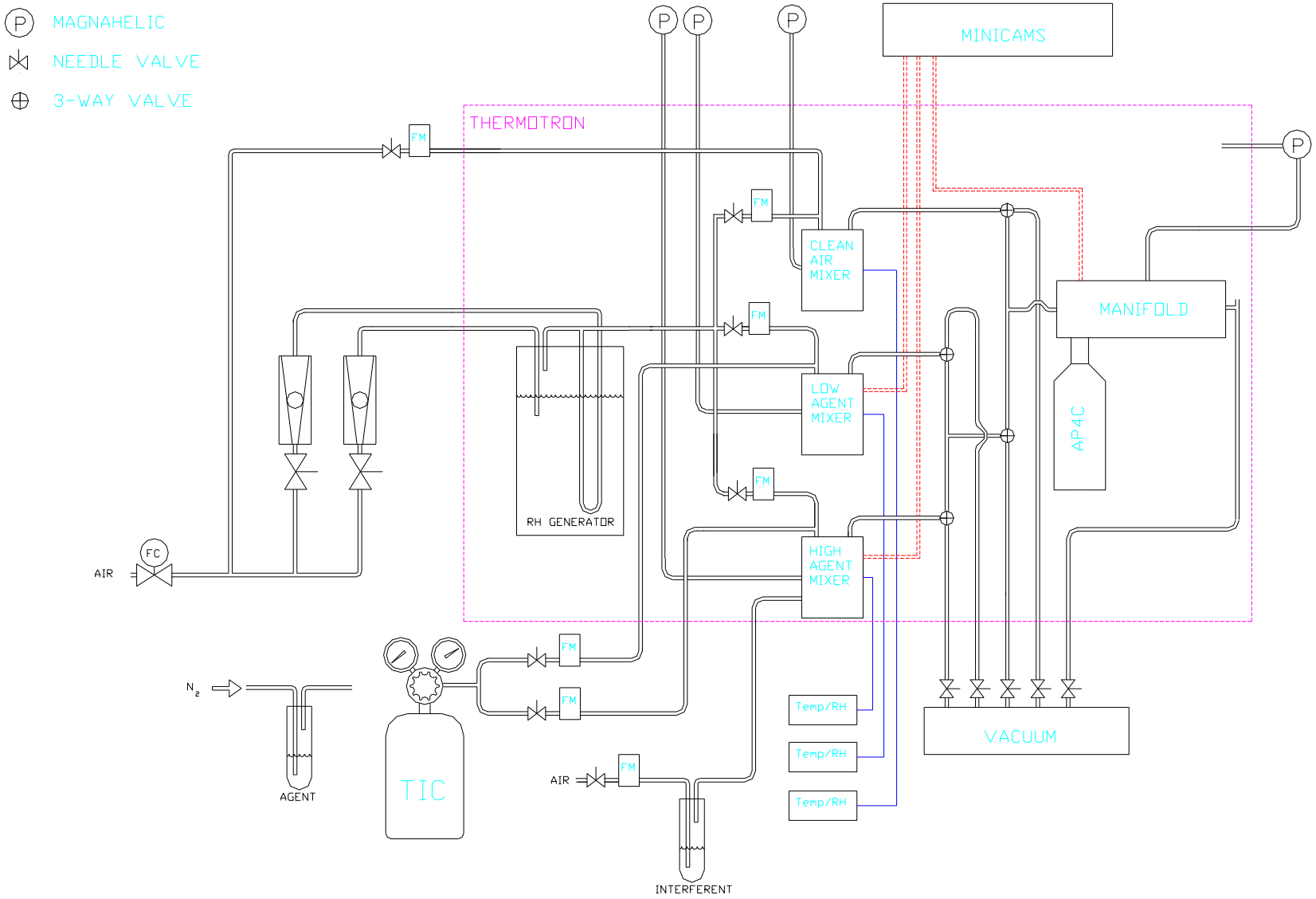


Figure 1 – Vapor Generation and Delivery System Schematic

Challenge vapors were provided to the manifold from where the detector could draw sample vapor out of the passing chemical laden air stream. A series of pneumatic valves controlled the introduction of clean air or challenge vapor in the manifold as required by test protocol. The system was designed to expose the detectors to the full challenge concentration (or clean air) within seconds of the valve actuation.

Dilution air was heated or cooled and humidified in accordance with specified test conditions. Temperature and relative humidity levels were monitored by a calibrated thermometer/hygrometer and recorded in real time throughout the duration of the test by a laptop computer running a LabView® data acquisition program. Effluent vapor from the manifold was vented into a certified chemical fume hood.

4.3 MINICAMS®

The Miniature Chemical Agent Monitoring System (MINCAMS®) was used for the analysis of chemical agents during these experiments. The MINICAMS® is an automated gas chromatograph equipped with a solid-sorbent thermal desorption inlet system and a flame photometric detector. Chemical agent vapors were collected onto a pre-concentrator tube (PCT) during a sampling period and thermally desorbed into the GC column for elution and detection. The MINICAMS® computer software recorded various data including elapsed time, sample flow rate, and agent mass detected allowing for computation of vapor concentration.

The MINICAMS® was operated using five-minute sample cycles and synchronized to sample from the challenge manifold during the AP4C agent challenge. The use of a manual Swagelok® valve allowed the MINICAMS® to monitor from any of several locations in the agent pathway including the high and low concentration agent mixers, the challenge manifold, and the environmental chamber. The MINICAMS® sample from the challenge manifold was collected near the AP4C's sampling location to ensure accurate and representative measurements of the airstream that the AP4C was sampling during challenge.

During this test program, CUBRC employed different methods to optimize results and ensure the accuracy of the system and the readings collected by the MINICAMS®. GB, which is a relatively small molecule (MW =140) and extremely volatile (22,000 mg/m^3 at 25°C), results in little carryover from one cycle to the next. During GB monitoring, the MINICAMS® measurements were taken alternately from the agent mixer and challenge manifold during clear

down and challenge, respectively. The measured agent in the challenge manifold (as drawn from a position near the detector inlet) matches closely with the agent concentration measured in the upstream mixer supplying the manifold. VX, a persistent agent and relatively large molecule (MW = 267) having low volatility (10.5 mg/m^3 at 25°C), requires maintaining a concentration in the agent mixer approximately 25% – 50% higher than the target concentration depending on the temperature. Upon agent challenge, the VX concentration measured at the detector was near target concentration. HD required a different method as measurements at IDLH concentrations are characterized by significant analytical carry over from one sample cycle to the next. The agent concentration at the mixer was established and then read solely from the challenge manifold during the testing. This allowed a cycle of "clear-down" for the MINICAMS® in between each challenge when there was no agent present in the challenge manifold.

4.4 Flow Controllers/Flow Meters and TICs

While the MINICAMS® was able to accurately measure the concentration of CWA vapor used in this program, the TICs required the use of certified, assayed stock gases in conjunction with NIST-traceable calibrated flow controllers and flow meters to obtain concentration. Stock gas concentrations were selected to allow for simple dilution to achieve the target concentration. Additionally, ordering a diluted concentration allowed for safe handling of the chemicals. All chemicals were provided by Custom Gas Solutions located in Durham, NC. The chemicals and concentrations of the stock gases are listed in Table 7:

Table 7 – Stock TIC gases

Chemical	Concentration	Balance
CK	5042.52 mg/m^3 (2001 ppm ± 40 ppm)	Nitrogen
AC	5497.7 mg/m^3 (4997 ppm ± 100 ppm)	Nitrogen
Cl_2	2897.1 mg/m^3 (999 ± 20 ppm)	Nitrogen
SA	3183.62 mg/m^3 (998 ppm ± 20 ppm)	Nitrogen

4.5 AP4C

According to the manufacturer (Proengin), the AP4C (Figure 2) is a portable chemical contamination control device used to directly detect chemical agents in the form of vapor, aerosols, dust, and with an attachment (not tested), liquid.

Figure 2 – AP4C Detector

The detector is a flame spectrophotometer in which hydrogen is burned in a combustion chamber. It operates by pulling a continuous stream of air into the combustion chamber where it is burned. The light from the flame is passed to a diffraction grating and split into its component spectrum. The spectrum is then passed onto a detection grid. The signature spectrum in the flame and their luminosity are measured and processed in near real time. When a TIC or agent is detected, visual indication is provided by a 5 bar light readout on top of the instrument (Figure 3).

Figure 3 – AP4C display

Simultaneously, the raw data (measured concentrations) for each AP4C detection channel is processed and may be monitored and downloaded to a computer in real-time via a proprietary

software program provided by Proengin using a serial cable connection on the instrument. Proengin personnel provided training on the operation and handling of the AP4C unit prior to testing by CUBRC. Proengin also provided spare hydrogen cylinders and batteries for the start-up and battery life measurements, as well as an external hydrogen feed line and external power (12-24V DC) connection to more efficiently conduct routine testing on the detector. No calibration was required.

The AP4C tested on this program was denoted with serial number 1636_3367.

5. PROCEDURES

Detailed standard operating procedures (SOPs) which outlined the step-by-step test procedures were prepared and used during the evaluation of the detector. These procedures were reviewed and approved by CUBRC for both technical accuracy and safety. The AP4C was operated by CUBRC personnel as directed during a training session presented by Proengin representatives.

The tip of the removable sampling nozzle of the AP4C was mounted inside the challenge manifold through a drilled out port so that an air-tight seal was created around the shaft of the nozzle, completely isolating the rest of the AP4C from the agent challenge. Proengin advised that the pressure inside the manifold was required to be very close to the exterior pressure of the manifold for proper operation of the AP4C. This was accomplished by employing a "soft vacuum" connection to the manifold to collect the agent vapors passing through the manifold while maintaining an open connection to the test chamber. During the testing, there was a constant pressure differential of 0.1" H_2O (0.00025 atmosphere) in the system, with the manifold having the higher pressure in relation to the test chamber ambient pressure. Of note, however, is that the total flow into each mixer and ultimately the challenge manifold was reduced to 5 LPM, a deviation from the QAPP stated flow rate of 10 LPM, to accommodate the AP4C pressure requirement.

The AP4C can be equipped with an external hydrogen feed line and external power supply that enables virtually unlimited use for testing without the need to replace and refill the hydrogen cylinder or battery. In pre-test discussions, it was decided that this would be the most convenient and effective option given the amount of tests and the projected "on" time of the detector. The Hot Start/Cold Start and Battery Life experiments were conducted with the

supplied batteries and hydrogen cylinders. All other experiments were conducted using the external H_2 feed line and external power supply.

5.1 Pretest Activities

Before testing each day, the clocks on the computers that collected the airstream temperature and relative humidity data and the AP4C data were synchronized to the calibrated master test clock. The AP4C data collection software was started followed by the detector and the time to reach "ready" status of the AP4C was recorded. The air flows and vacuums to the system were adjusted so that the pressures in each mixer (clean, low agent, high agent) were at 1.8" H_2O. During the initial system prove-out, this pressure was found to provide optimum system performance throughout background, challenge high, and challenge low modes. Flow to each mixer was set for a final rate of 5 LPM by adjusting the needle valve directly upstream of the flow meter.

5.2 Challenge Concentration

CWA: A calibrated MINICAMS® was used to measure challenge concentrations for the CWA tests. Stock solutions (500 ng/μL) were prepared in solvent from neat agent. The stock solutions were serially diluted into four calibration standards having concentrations of 50, 5.0, 0.5, and 0.05 ng/μL respectively. Internal procedures were followed to verify the precision and accuracy of the MINICAMS® prior to calibration. Known quantities of calibration standards were manually injected into the MINICAMS® to generate calibration curves on each test day. At the end of each test day, verification calibration injections verifying the target concentration measurement were made to determine and correct for possible instrument drift.

TIC: Certified assayed stock gases were diluted in air to calculated theoretical desired concentrations through calibrated flow meters and flow controllers and delivered to the challenge manifold.

5.3 Response and Recovery Time Tests

The system was configured to deliver 5 LPM of air through both the clean air and the high agent mixers (there was no flow into the low agent mixer) at 22°C and 50%. The high agent mixer contained the target chemical IDLH concentration (high concentration) (Table 1). During

TIC testing, the system was considered stable after 20 mixer air exchanges with no adjustments of dilution or vapor flow. For the 1 liter mixer internal volume it required 4 minutes at 5 LPM flow rate to achieve the 20 air exchanges. During CWA testing, the system was considered stable after two successive agent mixer MINICAMS® readings which differed by less than 10% of the target concentration. Upon completion of all pretest activities and stabilization of test conditions, the AP4C sampled clean, conditioned air for a minimum of 5 minutes. At this point, the vapor challenge was introduced and the timer was started. The time for the AP4C to reach alarm status was recorded, and the challenge continued for 5 minutes. At the end of the 5 minute challenge, the valves were actuated to provide clean air to the AP4C and the time for the detector to return to its non-alarm status (i.e. recovery time) recorded. The detector sampled clean air for a minimum of 5 minutes before the next challenge was initiated. There were 5 challenges at each test and environmental condition.

Once the high agent concentration challenges were complete, the system was configured to deliver 5 LPM into three mixers (clean, high agent, and low agent) at 22°C and 50% RH. The low agent mixer was configured to contain the PEL concentration (low) (Table 1) of the target chemical and all concentrations were allowed to stabilize. The detector sampled clean air until the zero baseline (non-alarm status) condition was reached. At this point, the detector was exposed to alternating challenges from the high and low agent concentration mixers with each challenge lasting 5 minutes. There were a total of five cycles of alternating high/low challenges and the response of the detector at each challenge was recorded. Due to the difference in concentrations between the two levels (IDLH vs. PEL), the MINICAMS® was used to monitor only IDLH challenges as the carryover from high concentration would grossly contaminate the subsequent low concentration measurement. Therefore, the low concentration was monitored pre-test with the MINICAMS® until stable, followed by the MINICAMS® dedicated to measuring the high concentration challenges only.

5.4 Response Threshold Tests

The detector was challenged to identify the lowest concentration (at 22°C and 50% RH) at which it would respond. The starting challenge concentration was determined by using the manufacturer's reported detection level values (see Table 8 below).

Table 8 – Reported Detector Sensitivities

TIC/CWA	Concentration (mg/m^3)
CK	NR
AC	10
SA	1.5
Cl_2	NR
GB	0.01
HD	0.5
VX	0.01
L	4.2

NR = Not Reported

If no response was observed after the five minute challenge, the agent concentration was increased by a factor of two and the exposure cycle repeated. This method continued until a response was observed or until IDLH is exceeded. Conversely, if a response was observed within five minutes on the first exposure cycle, the agent concentration was decreased by a factor of two until 1) the detector could no longer detect and identify the chemical, or 2) until CUBRC's vapor generation system can no longer hold a stable concentration at such low levels. Once the minimum challenge concentration that elicited a signal had been identified, that concentration was considered the instruments' response threshold.

5.5 Interferent Effects

Interferents were delivered to the challenge manifold at 50 mL/min under the control of an independent delivery system. In this program, interferent was presented as a percent of total flow (% headspace). At the humidified air flow of 5 LPM (22ºC/50% RH), the interferent was present at a 1% headspace concentration. The detector was first challenged in the absence of agent with five cycles of alternating interferent only and clean air challenges to evaluate any potential false positive responses and gather baseline response to each interferent. The interferent was then mixed with the chemical vapor challenge at IDLH levels and delivered simultaneously to the challenge manifold as a combined challenge for the detector to analyze. The detector was exposed to five challenge cycles.

The interferents paint vapor, ammonia, air freshener, and N,N-Diethylethanolamine (DEAE) were introduced into the high agent mixer from a glass impinger that contained approximately 5 mL of each interferent which allowed for the end of the inlet stem to become submerged in the liquid. Air was passed through the liquid at 50 mL/min and the outlet of the impinger was connected directly to the high agent mixer.

To introduce the engine exhaust, a 4" diameter x 6' long flexible exhaust pipe was placed over the tailpipe of an automotive vehicle (2005 Chrysler Town and Country Minivan). The vehicle was allowed to run for a minimum of 30 minutes prior to the first exhaust interferent challenge. A ¼" PFA tube was placed inside the pipe extension and connected to a vacuum pump that would serve to draw the exhaust from the vehicle and deliver it to the agent delivery system at a controlled rate of 50 ml/min. Prior to implementing the vacuum pump to deliver the exhaust interferent, the detector was challenged with only the pump operating in line to verify that the vacuum pump alone did not cause a response from the detector.

The final delivery method deviates from the QAPP which had described ducting the exhaust to a 55-gallon drum and drawing from that drum into the challenge delivery. The back-pressure created from the drum caused the vehicle engine to labor. To prevent damage to the engine, the alternate method described above was employed.

The following describes the exact interferents used:

- **Ammonia:** Great Value™ Ammonia. Lot 09147 21:06A
- **Paint:** Dutch Boy® Home™ Interior Premium Latex Wall and Trim Enamel, Semi-Gloss. Brilliant White. Batch PP2898L 01125CS
- **Air Freshener:** AirWick® Crisp Breeze® Scented Oil refill EM9082
- **DEAE:** Aldrich, N,N-Diethylethanolamine, 99.5+%. Batch 82896EJ. Cas No. 100-37-8.
- **Exhaust:** Gasoline engine exhaust from a 2005 Chrysler Town & Country fueled with 87 Octane gasoline containing 10% ethanol.

5.6 Hot Start/Cold Start

The detector was stored at room temperature (22°C) for at least 12 hours prior to startup. The detector was powered up under battery power and readied for a challenge. The elapsed time from power-up to "ready" was recorded. The detector was powered down for 15 minutes and the process repeated four more times.

In addition, the detector was placed into an environmental chamber held between 5 and 8°C and allowed to sit overnight. The startup delay time was measured as described in the previous paragraph. This test was conducted once per day for a total of five (5) days throughout the course of testing. The detector also was placed into an environmental chamber held at 40 ± 3°C and allowed to sit overnight. The startup delay time was measured as described in the previous paragraph. This test was conducted once per day for a total of five (5) days throughout the course of testing.

After the detector had been subjected to a cold or hot environment overnight, the detector was powered on under battery power and an internal H_2 cylinder. The time to "Ready" was recorded as described above. The detector was then removed from the temperature extreme and immediately connected to the challenge manifold and connected to the external power supply and external H_2 feed line and subjected to five (5) alternating CK (at IDLH levels) and clean air challenges at 22ºC/50% RH. The startup delay time (one), response times (five), stable readings (five), and recovery times (five) were recorded.

5.7 Battery Life

To assess the continuous operation of the detector and batteries, new batteries and a fresh H_2 cylinder were installed. The detector unit was powered up and when ready, challenged with CK at 22ºC/50% RH as described in Section 5.3. The response from the detector unit was recorded. The detector was then allowed to sample 30 minutes of clean, humidified air followed by another chemical challenge. This procedure was repeated until the response time doubled, or the entire operational time reached 12 hours. The total time in operation represented the measure of battery life.

6. RESULTS

6.1 Response and Recovery Time

The response time of the AP4C for each of the challenges is presented in Appendix C. For each chemical with the exception of Cl_2, the detector responded within 5 minutes of challenge at the IDLH level at every environmental condition. Cl_2 did not elicit a response at the IDLH level, as Proengin stated prior to testing that the AP4C would not. The remaining planned tests with Cl_2 were removed from the matrix. Listed in the Appendix C tables are the chemical

and concentration of the challenge, the time for the detector to alarm, the channel that alarmed, the reported concentration, and the time for the detector to clear to a non-alarm status after the termination of the challenge. The AP4C readings were taken every second and fluctuated about a certain baseline level. At the onset of a vapor challenge, the AP4C responded immediately with an increase in the respective channel. The response increased steadily until a maximum level was reached, at which point the readings began to fluctuate again in equilibrium at this new level. When calculating the measured detector response, the readings from the AP4C were taken such that all data after this first inflection point until the end of the challenge were selected. The arithmetic mean of these points was considered the detector response and this value is reported as such in the data tables of Appendix C. It should be noted that the detector reports amounts on each channel in mg/m^3 of *compound*, not the actual concentration of *chemical*.

When testing against HD and VX, there were several challenges where the detector response would fluctuate near the alarm threshold level and only exceed it briefly. Although the detector did alarm at all challenges at the IDLH level, there were some instances that the detector was not in alarm status when the challenge was terminated and therefore the clear down time was not able to be discerned. In the challenges where this occurred, the recovery time is listed as 00:00.

As discussed in Section 4.4, there was no method for actively measuring the concentration of TICs delivered to the challenge manifold. Therefore, the use of calibrated flow controllers and flow meters was strictly employed to provide the desired concentration of chemical to the system. When testing against the CWAs, the challenge manifold was actively monitored for the vapor concentration. Those measurements are listed in the tables in Appendix C.

6.2 Response Threshold

The starting concentration for AC, GB, and HD was selected using the manufacturer's stated detection limit as stated in Table 4. As there is no reported detection limit for CK, the starting concentration was set to 10 mg/m^3, which was based on the detection limit for AC. Also, since the detector was alarming at the PEL levels of SA during the high/low alternating challenges of the response time experiments, this level (0.2 mg/m^3) was selected as the starting concentration for SA although this was lower that the reported detection limit of 1.5 mg/m^3. All

tests were conducted at 22°C and 50% RH. The MINICAMS® monitored the actual challenge concentration of CWA challenge and the concentration of the TICs was determined by calculating the theoretical concentration using the calibrated flow meters.

During the response threshold test for CK, while sampling of clean air prior to the first challenge, the baseline on the HNO channel was approximately -6.5 mg/m^3. Even at the lowest level tested (10 mg/m^3), the detector responded in this channel (signal increased to -2.77 mg/m^3) but did not alarm. It is possible that the low initial baseline caused the detector to not alarm although that concentration of CK did elicit a noticeable response from the detector when evaluating the raw data file. This agent (CK) was the only chemical tested where the initial concentration did not result in an alarm and subsequent challenges were at higher concentrations. All other chemicals tested resulted in an alarm at the starting concentration and subsequent challenges were conducted at lower concentrations.

Of note during the response threshold study was that at the HD concentration of 0.476 mg/m^3, the detector did alarm at 4 minutes, 27 seconds into the challenge. However, the detector remained in the alarm status for only 1 second, at which point it returned to its non-alarm status and remained for the duration of the challenge. Because the detector did indeed alarm during the challenge, this concentration is listed as the threshold value (Table 9 and Appendix C Table C.13)

The final detection limits for each agent tested is listed in Table 9 below.

Table 9 – Response Threshold Results Determined for the AP4C.

TIC/CWA	Threshold Level (mg/m^3)	Proengin Reported Detector Sensitivity (mg/m^3)
CK	30.0	NR
AC	10.0	10
SA	0.05	1.5
GB	0.0107	NR
HD	0.476	0.01
VX	0.00904	0.5
L	1.35	1.5

6.3 Temperature and Relative Humidity Effects

The AP4C did not readily show effects from temperature or relative humidity. For a detailed analysis and discussion on the effects of these environmental parameters, see Appendix B.

6.4 Interferent Effects

The interferents ammonia and DEAE both elicited an alarm response from the AP4C in the HNO channel in the absence of any other chemicals. The response of the detector to the 1% headspace ammonia concentration was substantially high enough (>100 mg/m^3) that it could have masked any response due to agent on the HNO channel. The response to DEAE was comparatively low enough (~ 10 mg/m^3) that a higher response was given from the detector when both DEAE and chemical vapor were present. The interferent results are presented in Table C.3 (Appendix C).

Of note was the presence of ammonia seemed to depress the response of the AP4C to HD. While the detector alarmed in the sulfur channel when challenged with HD alone at the IDLH level, it did not alarm in that channel at the same concentration in the presence of ammonia. However, the presence of HD at IDLH levels was verified via MINICAMS® and the detector did alarm in the HNO channel, presumably due to the ammonia. The other interferents did not appear to affect the AP4C.

For further analysis and discussion of the interferent effects, see Appendix B.

6.5 Hot/Cold Start

The detector was incubated overnight at 22°C with batteries and an H_2 cylinder installed. It was placed on a lab bench and powered on. The time until it reached "ready" status was recorded under the ambient laboratory conditions. The detector was then placed back at 22°C for 15 minutes and then the start up sequence repeated until a total of 5 measurements were obtained. The average time for the detector unit to start up at ambient conditions was 45 seconds (see Appendix C, Table C.21).

The start up delay times were also measured at elevated temperature (40°C; avg. time = 1min, 50 sec) and at lowered temperature (5°C; avg. time = 3min, 02 sec). The response time to a CK challenge at IDLH levels at 22°C and 50% RH was also measured immediately after

removing the AP4C from these temperature extremes. The response time did not seem to be affected greatly by these temperature extremes as stated below in Table 10.

Table 10 – Response Times.

CK average response time at ambient conditions:	15 seconds
CK average response time at elevated temperature:	18 seconds
CK average response time at lowered temperature:	15 seconds

6.6 Battery Life

Proengin provided CUBRC with a set of new batteries (Lot No. 09.042.D06) and a new hydrogen cylinder (S/E 30102636134). Upon receipt these items were stored at room temperature. These items were installed into the detector at the start the battery life test, and the detector powered up and readied for a CK challenge at IDLH levels (50.0 mg/m^3) at 22ºC/50% RH. All results were obtained visually as the detector was not equipped to monitor or collect data in real time. Challenges were 5 minutes in duration followed by a 30 minute clear down period where the detector sampled clean humidified air. The AP4C first challenge response time was 9 seconds and it responded to a level of 2 lights (1 yellow, 1 red). At the end of the 12 hour test, the detector was still responding in 10 – 11 seconds and at the same level of 2 lights (1 yellow, 1 red). The detector was allowed to run another 2 hours (T = 14 hours total) with no degradation of response time or response level. At 22 hours, the detector was shown to have all 5 lights lit on the HD, HL channel and was unresponsive to a CK challenge. The data is presented in Appendix C, Table C.22.

7. DISCUSSION

At the beginning of the test program, the agent dilution and delivery system, as well as the AP4C, were contained within an insulated glove box located inside a fume hood. The initial detector tests were successfully conducted with CK at 22ºC and 50% RH, but it became apparent that this setup would not be able to maintain the temperature stability required for the remaining test temperature extremes of 5ºC and 35ºC. As a result, and as there would be minimal handling of the detector during testing, the system was transferred to the large Thermotron chamber which allowed for more rapid stabilization and temperature control.

An issue discovered during the initial system prove-out before testing began was thought to involve a pressure phenomenon with the detector nozzle mounted to the manifold. When the challenge was initiated, the small pressure change inherent in the valve system resulted in the detector changing from "ready" status to "waiting" where it stayed for approximately 30 – 40 seconds before returning to "ready" status. The possibility of pressure buildup in the challenge manifold as well as a strong negative draw on the challenge manifold due to the vacuum was eliminated by inserting a "T" connection between the challenge manifold and the vacuum manifold with a leg of the "T" open to the atmosphere. There was a concern that contents of the challenge manifold could escape into the test chamber through open leg of the "T". However, capping the open leg resulted in a drop in pressure within the challenge manifold, indicating that the vacuum draw was sufficient enough to prevent vapor from escaping the manifold and flowing into the chamber.

Although the AP4C detector often alarmed and cleared within seconds of the challenge being presented and removed, each challenge lasted a full 5 minutes in order for the detector to collect substantial amounts of data as well as to maintain consistency throughout the test program.

At times during testing it was noted that the HNO channel on the AP4C reported baseline levels near -10mg/m^3 during regular monitoring of the clean air in the challenge manifold. This was particularly evident in the response threshold studies for CK and may have affected the results. No correlation was found in environmental conditions, nor did investigation of the system setup reveal any potential causes for this. Efforts to intentionally create this negative baseline (using pressure increases/decreases and RH swings) were unsuccessful. Proengin representatives were notified of this phenomenon during testing and did not express any concern.

The interferent testing was conducted by establishing the target agent vapor concentration in the absence of interferent. When adding the interferent to the agent, the agent vapor concentration was not impacted except during the DEAE with VX trials. In this test, the pre-interferent agent challenge concentration of 0.02 mg/m^3 was established and upon the introduction of DEAE the MINICAMS® measured agent concentration increased nine-fold (estimated as response exceeded calibration curve) and AP4C response increased 650%. This enhanced response in agent concentration decreased over time, leading to the prevailing explanation that the DEAE was acting as a solvent and removing the residual VX from the walls

of the system pathway that had accumulated during the previous tests. Due to this phenomenon, the agent concentration was established while in the presence of the DEAE when conducting this test.

Only the ammonia and DEAE showed any effect on the AP4C when presented in the absence of agent, causing a false positive alarm on the HNO channel (see Appendix B). The AP4C reported mean concentrations of 124.27 mg/m^3 for ammonia and 9.81 mg/m^3 for DEAE. These levels were above the alarm threshold for the AP4C on the HNO channel. The other interferents did not cause a response from the AP4C when presented individually.

When introducing the ammonia vapor, on occasion, the ammonia bubbled up and into the stem of the impinger causing some liquid ammonia to condense in the delivery line. A 3/8" diameter felt pad was placed on the outlet of the impinger to absorb any liquid that may escape the impinger. Although care was taken that the bubbling was not violent, this created some instability in the concentration reported by the AP4C.

The establishment of the low concentration was not done during the VX testing as planned. Because of the significant difference in concentrations (0.02 mg/m^3 in the high mixer; 0.00001 mg/m^3 in the low mixer), the amount of residual agent in the system after the high challenge would be several magnitudes higher than the concentration in the low mixer. However, to fulfill the requirements of the test matrix as completely as possible, the system was set up with the IDLH concentration (0.02 mg/m^3) at 22^{o}C and 50% RH in the high agent mixer, and the AP4C was subjected to alternating challenges from this high mixer and clean air.

The detection of VX by the MINICAMS® employs the use of V-to-G conversion pads in the sampling pathway to convert VX into its G-analog. It is this G-analog that the MINICAMS® detects. At certain conditions such as at high water content or in the presence of certain interferents, the conversion pads may become affected and accurate measurements of concentration are rendered difficult to obtain.

In the presence of high water content (35^{o}C and >50% RH), the VX concentration can be difficult to ascertain as the possibility exists that in addition to the conversion pads becoming saturated with water and rendered inefficient, the VX itself may be hydrolyzed by the water. During the course of the testing, efforts were made to keep the measured concentration of VX within specifications. In order to do so, it was necessary to increase the amount of VX vapor delivered to the system. Although the MINICAMS® measured a concentration within normal

specifications (0.02 mg/m^3 ±_20%), the AP4C displayed a higher response in its phosphorus channel, presumably due to an actual higher concentration of VX.

Also, it was noticed that the presence of engine exhaust appeared to affect the VX concentration measurements taken by the MINICAMS®. During testing, the measured concentration was decreasing over time to a point where the concentration risked dropping below the 20% of target specification threshold. The amount of VX vapor delivered to the system was increased over the course of the 5 detector challenges. Although the MINICAMS® measured ~0.019 mg/m^3 during the challenges, the response of the AP4C was elevated as compared to the readings without exhaust present. At the end of this series of challenges, the exhaust was removed and a measurement of 0.0238 mg/m^3 was recorded by the MINICAMS®. The exhaust did not appear to affect the AP4C otherwise (See Appendix B).

A Technical Systems Audit was conducted by the CUBRC QA/QC manager during the course of testing. A review of the sampling and analysis methods used was performed, a comparative check of actual test procedures to those specified in the plan was made, and a review of data acquisition and handling procedures was done. Additionally data quality objectives were checked, calculations verified and adherence to CUBRC internal quality procedures monitored. The full report can be obtained upon request.

APPENDIX A: Manufacturer's Product Information Sheet

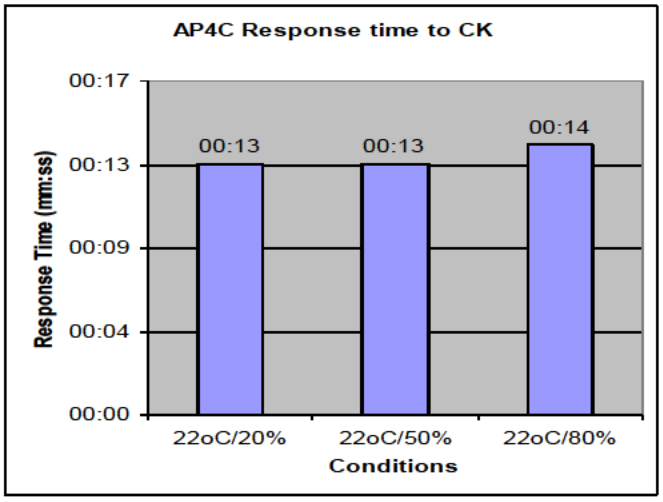
APPENDIX B: Analysis of Data

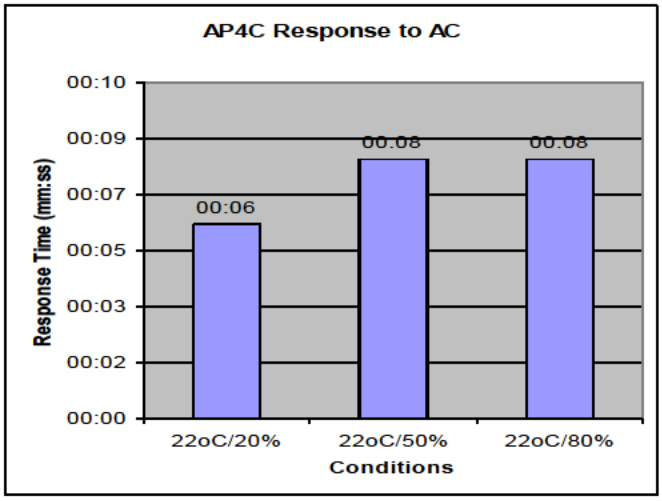
This appendix contains graphical displays of the tests in the response and recovery time experiments as well as the interferent effects experiments. The values displayed are the arithmetic mean of five replicate samples. Shown in the figures are comparisons in response times and reported concentrations due to changes in humidity (at a constant temperature) and temperature (at a constant humidity). During several experiments, it was difficult to calculate the mean of the recovery time as the detector was already in the "alarm off" mode at the conclusion of the challenge. The recovery times were not directly compared, but may be evaluated from the data in Appendix C.

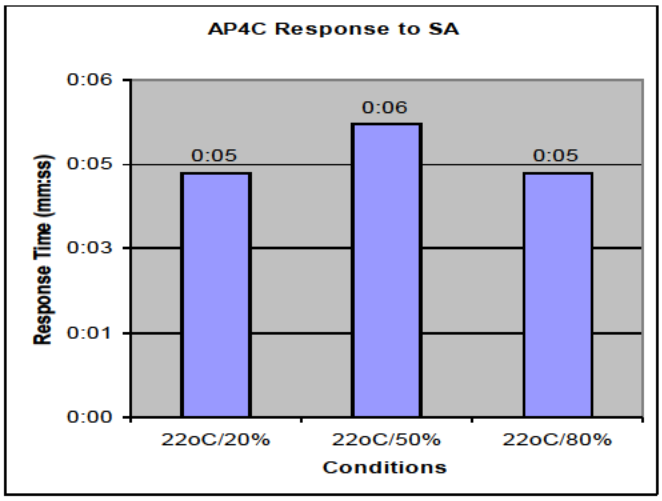
B.1 Humidity Effects:

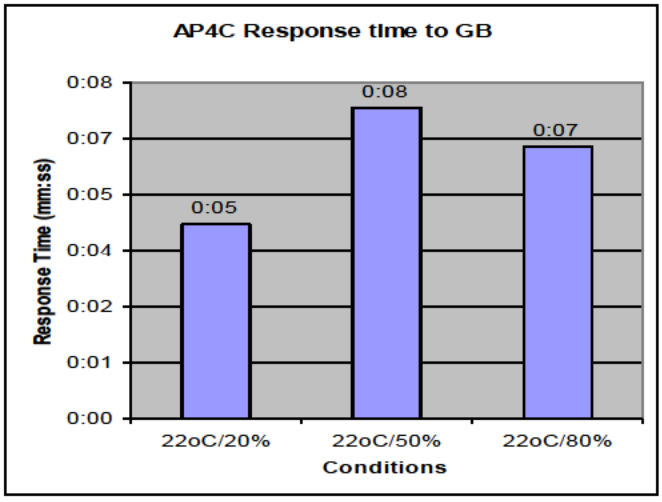
Effect on response time: There was no significant effect of humidity on the AP4C's response time to any of the agents tested as shown below:

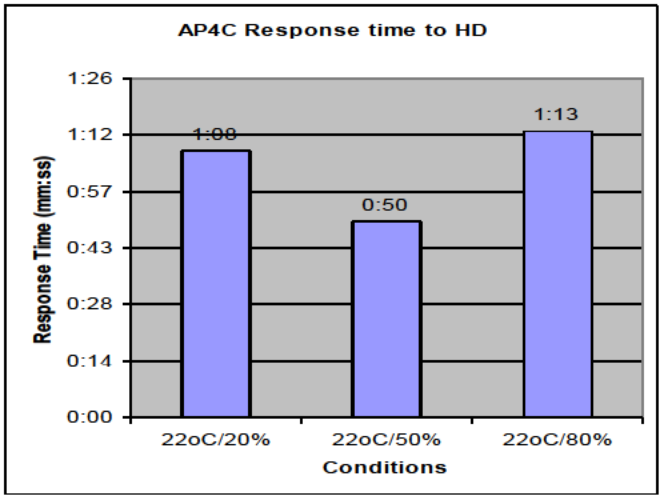
Figure B.1 – Effect of Humidity on response times

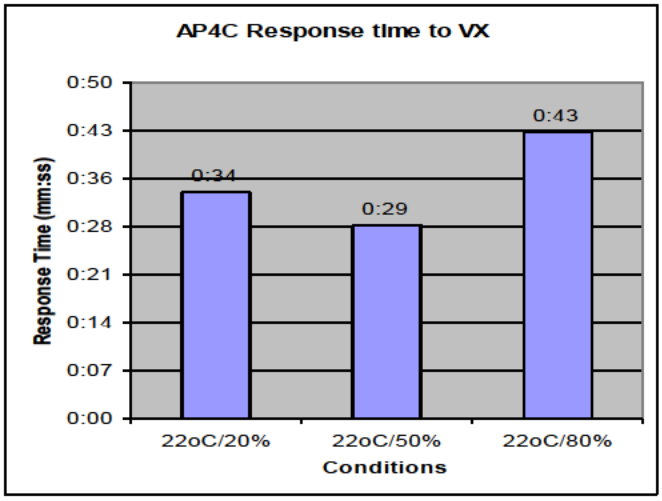



AP4C Response to AC
Response Time (mm:ss)
00:10
00:09
00:07
00:05
00:03
00:02
00:00
00:06
00:08
00:08
22oC/20%
22oC/50%
22oC/80%
Conditions


AP4C Response to SA
Response Time (mm:ss)
0:06
0:05
0:03
0:01
0:00
0:05
0:06
0:05
22oC/20%
22oC/50%
22oC/80%
Conditions

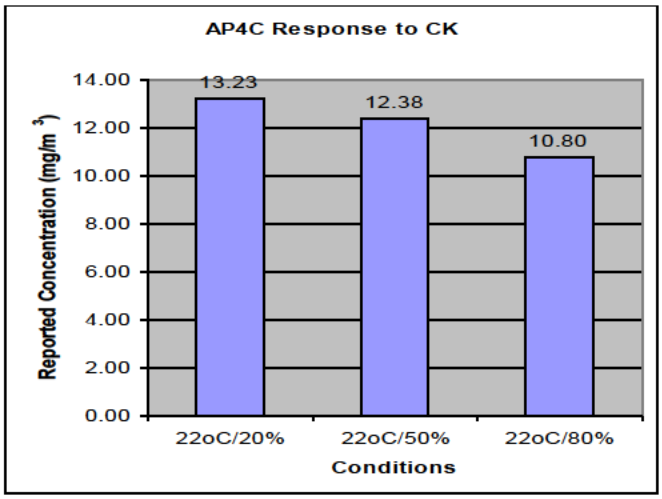

AP4C Response tIme to GB
Response Time (mm:ss)
0:08
0:07
0:05
0:04
0:02
0:01
0:00
0:05
0:08
0:07
22oC/20%
22oC/50%
22oC/80%
Conditions

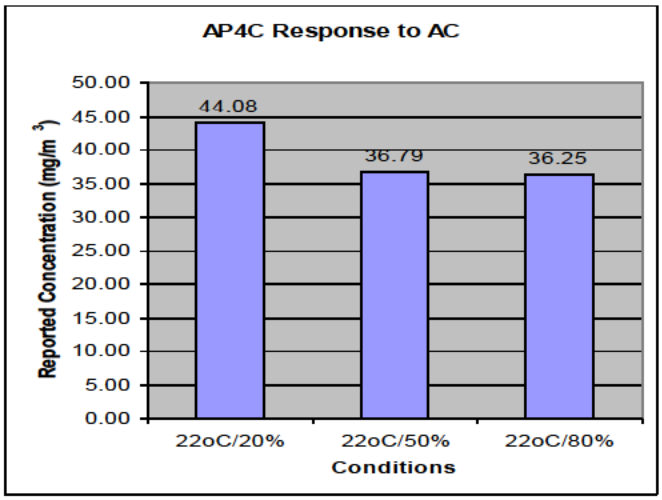


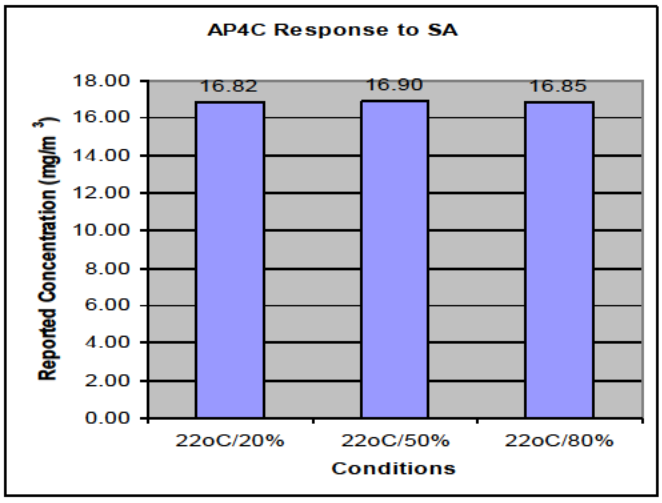


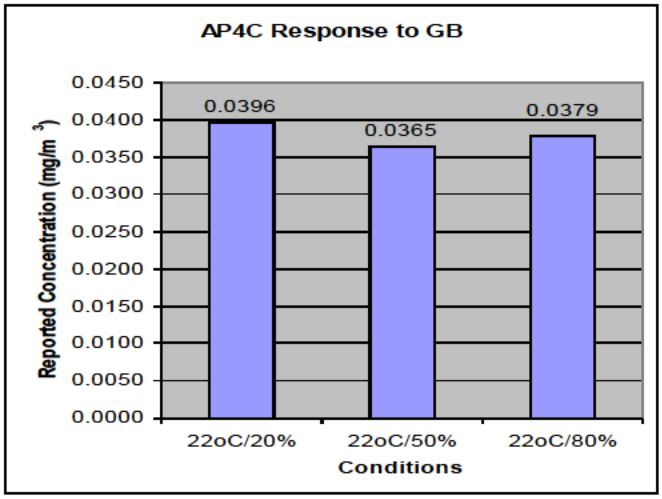
Effect on reported concentration: In addition, the reported concentration did not appear to be significantly affected by changes in humidity:

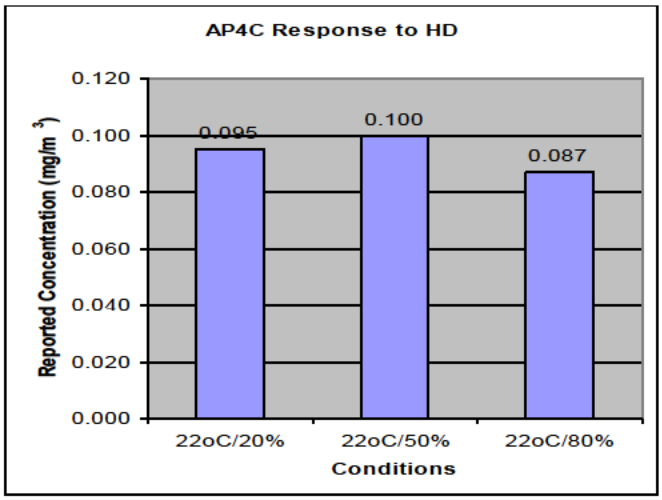
Figure B.2 – Effect of humidity on reported concentration

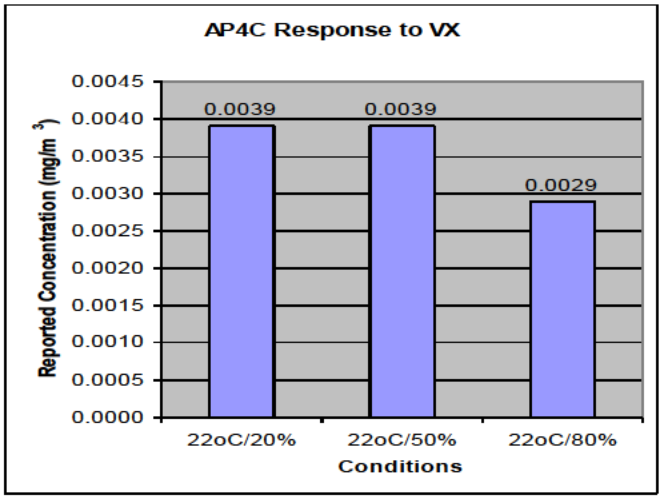










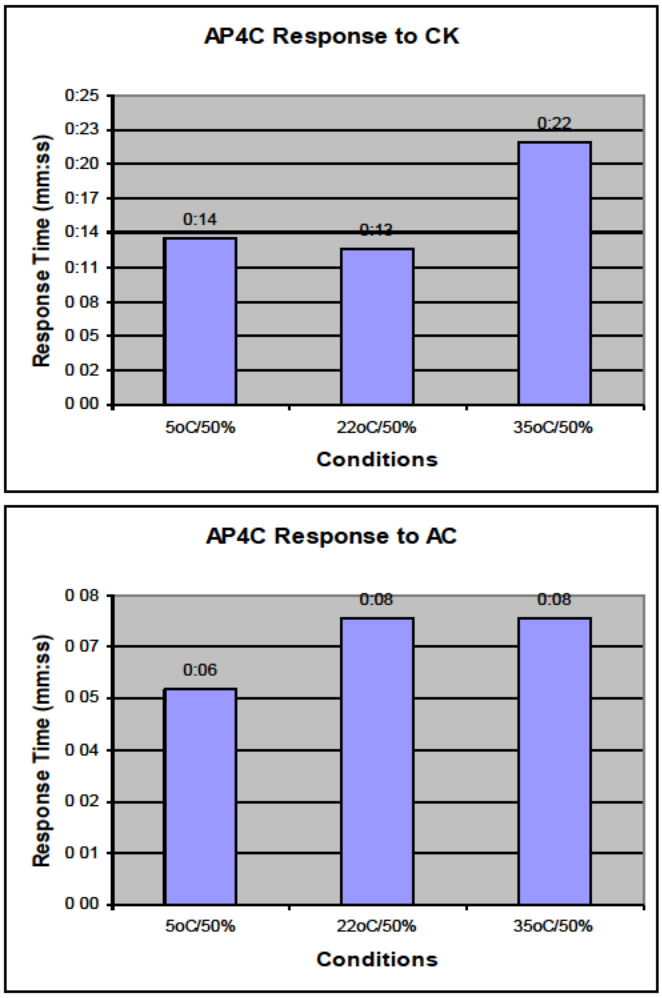


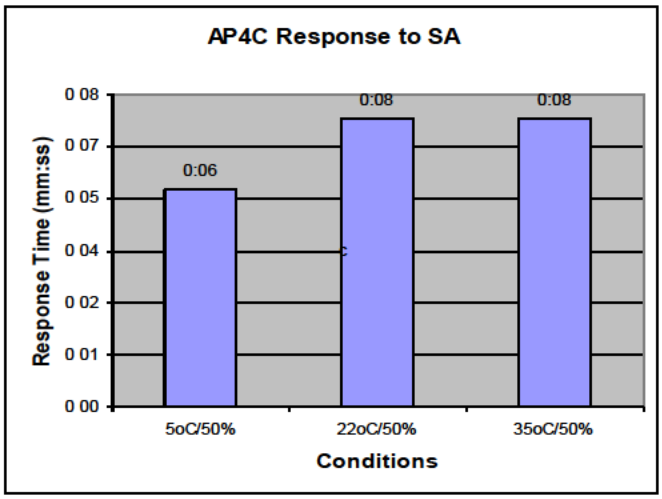
B.2 Temperature Effects:

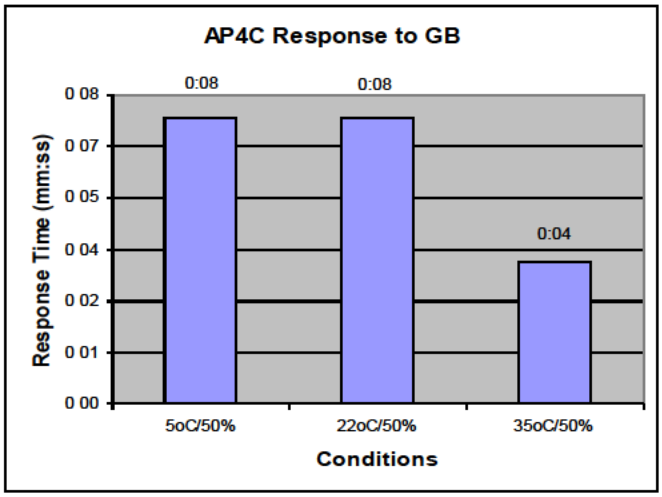
Effect on Response Time: While differences in the response time of the AP4C did appear at different temperatures, it is reasonable to believe that these times are affected by the

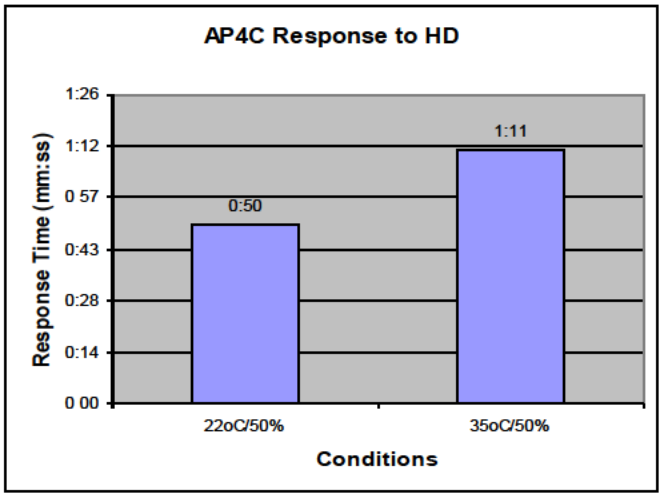
nature of the agent and the delivery system itself. The primary effect of temperature can be seen with VX at 5ºC. As this agent is a low volatility agent, it is not unexpected that this agent would take more time to move through the delivery system and reach the AP4C despite efforts to keep the path length as short as possible.

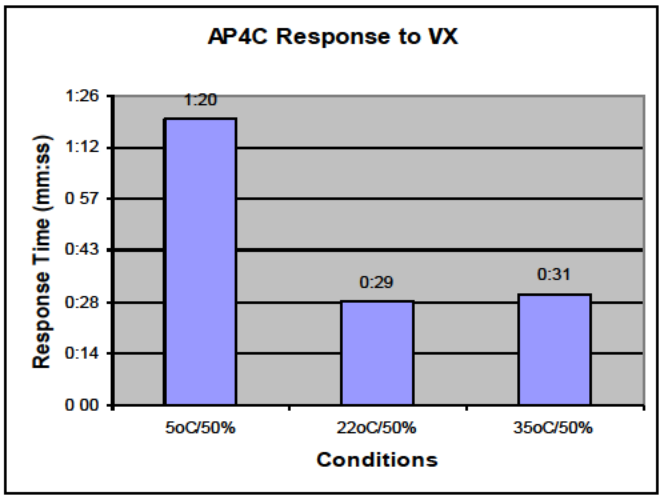
Figure B.3 – Effect of Temperature on Response Times




AP4C Response to SA
Response Time (mm:ss)
0 08
0 07
0 05
0 04
0 02
0 01
0 00
0:06
0:08
0:08
5oC/50%
22oC/50%
35oC/50%
Conditions

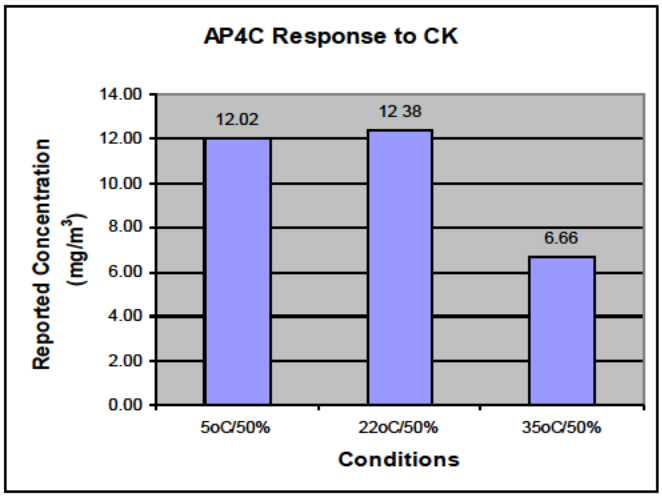

AP4C Response to GB
Response Time (mm:ss)
0 08
0 07
0 05
0 04
0 02
0 01
0 00
0:08
0:08
0:04
5oC/50%
22oC/50%
35oC/50%
Conditions

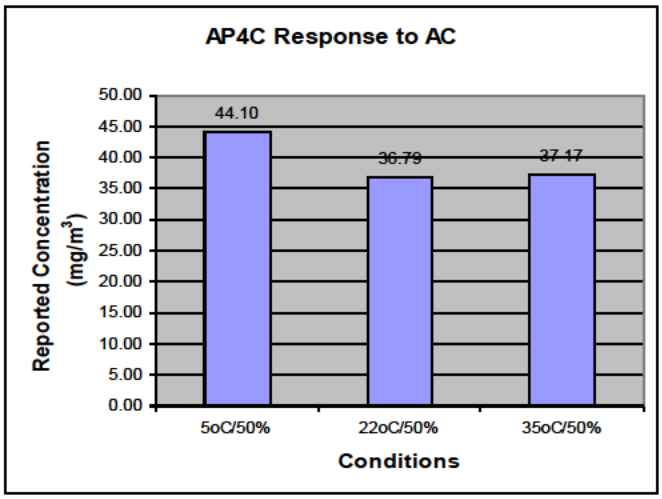

AP4C Response to HD
Response Time (mm:ss)
1:26
1:12
0 57
0:43
0:28
0:14
0 00
0:50
1:11
22oC/50%
35oC/50%
Conditions

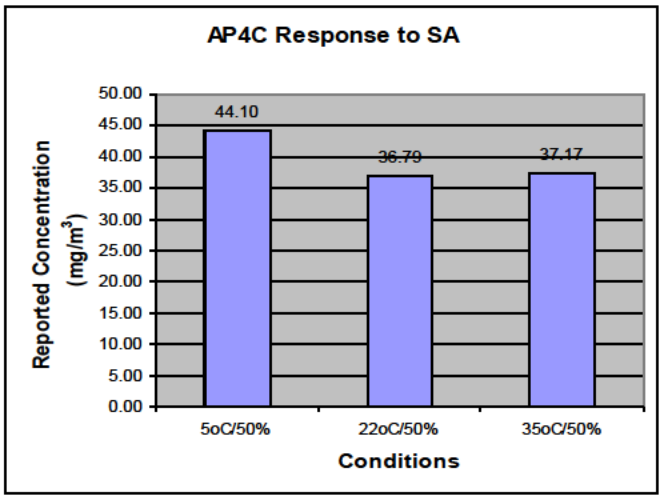


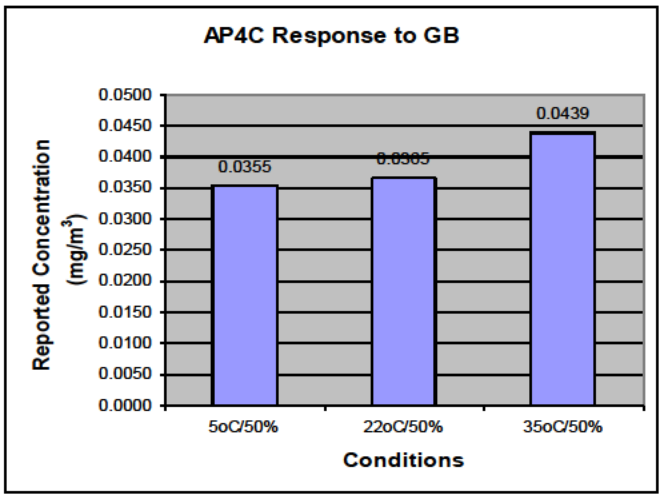
Effect of temperature on reported concentration: Here there is a noticeable effect on the reported concentration of VX at 5ºC. It is reasonable to believe that this is a true effect of temperature affecting the AP4C as the VX target concentration was verified (0.02 mg/m^3) prior to introducing the challenge as well as during the challenge as measured by the MINICAMS®.

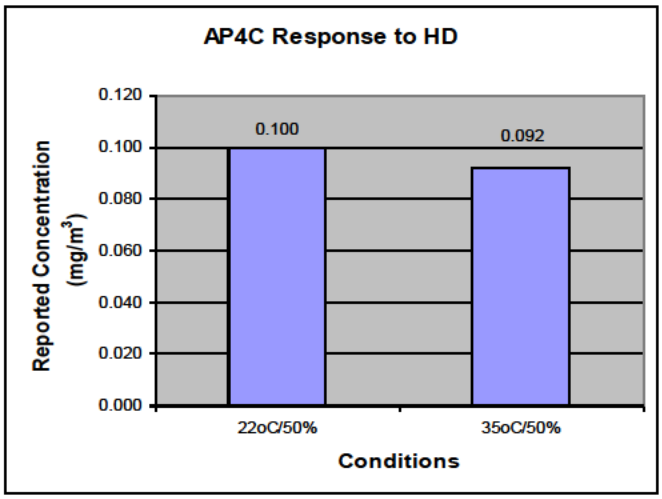
Figure B.4 – Effect of Temperature on Reported Concentration

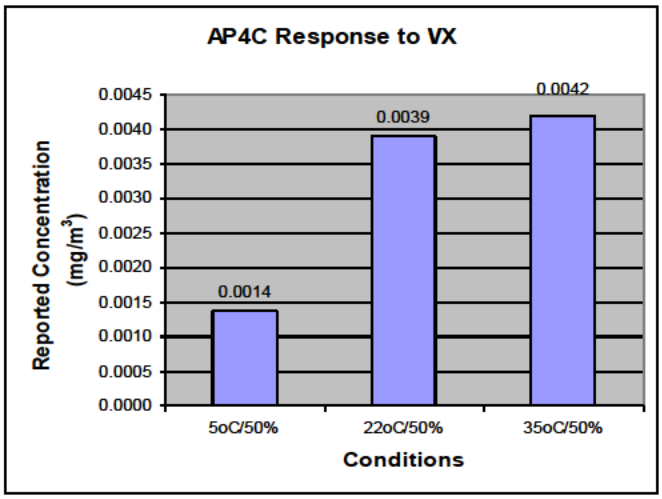










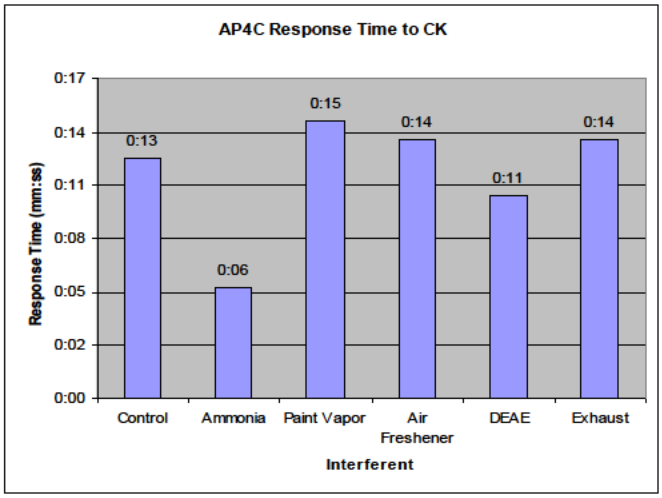


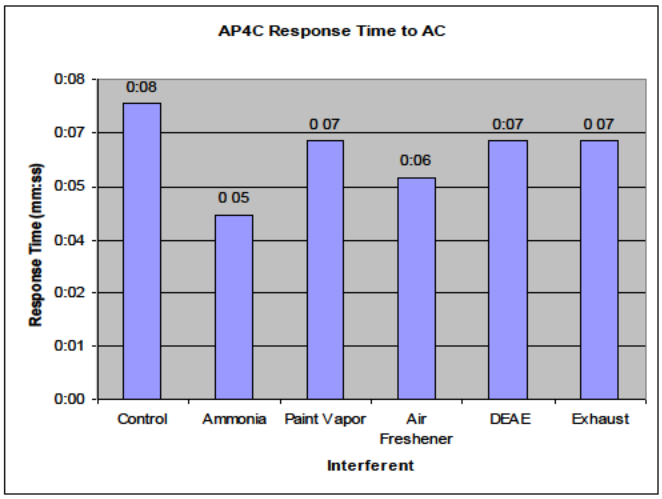
B.3 Interferent Effects:

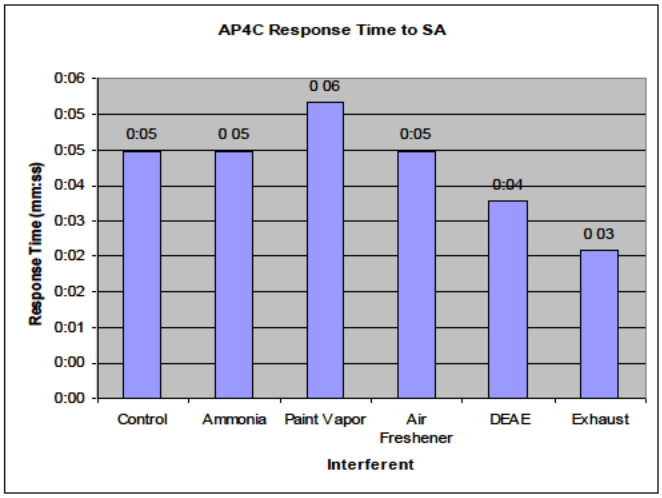
Effect of interferents on response time: The interferents did not significantly affect the response time of the AP4C when compared to that of the agent in the absence of interferent. The primary effect was seen with the interferents (ammonia, DEAE) and the chemicals (CK, AC) that alarm in the HNO channel. The additive effect of ammonia and DEAE to the challenge perhaps could have allowed the AP4C to alarm moderately faster than in the control experiment. However, as the AP4C was already alarming quickly after the onset of challenge, this effect may not be significant.

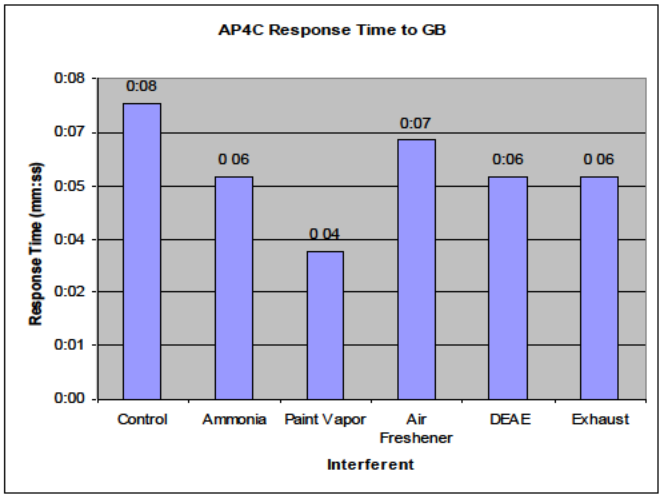
Of note is the fact that the ammonia interferent completely suppressed the AP4C response to HD as noted in Section 6.3.

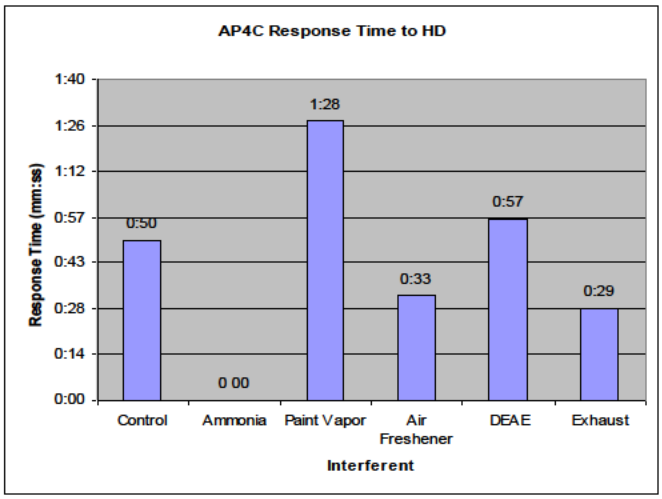
Figure B.5 – Effect of Interferents on Response Times

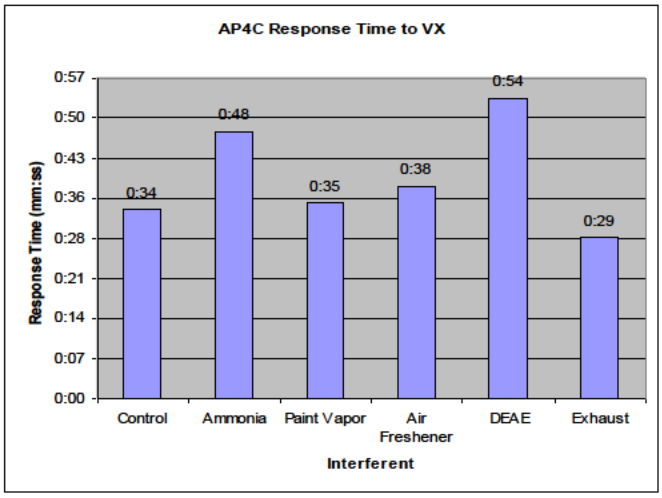








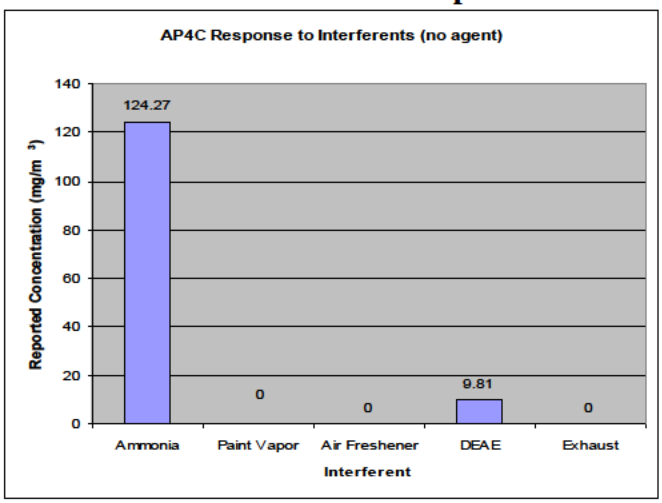


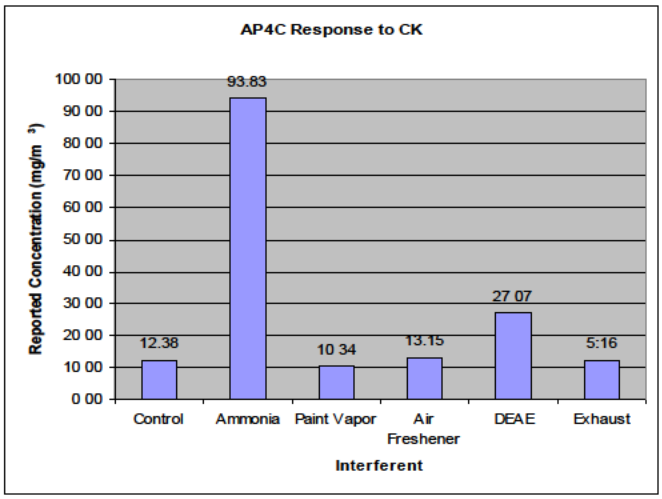


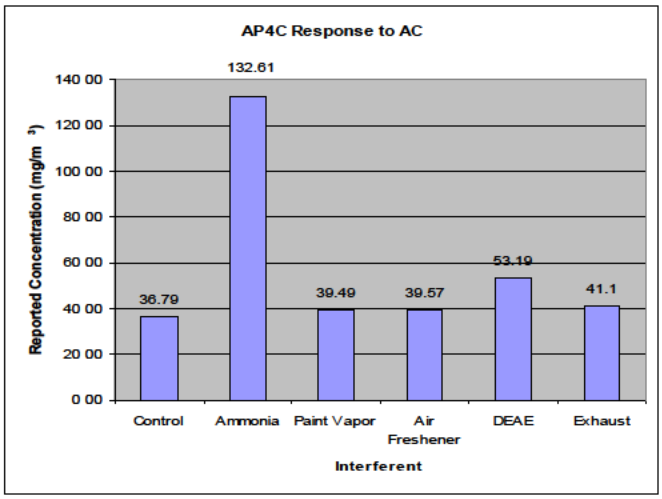
Effect of interferents on reported concentration: As stated earlier in this report, the ammonia had the greatest effect on the readings of the AP4C. As can be seen from the data below showing the concentration read by the AP4C for CK and AC in the presence of ammonia, the response is significantly higher than the other interferents. This is most assuredly due to the

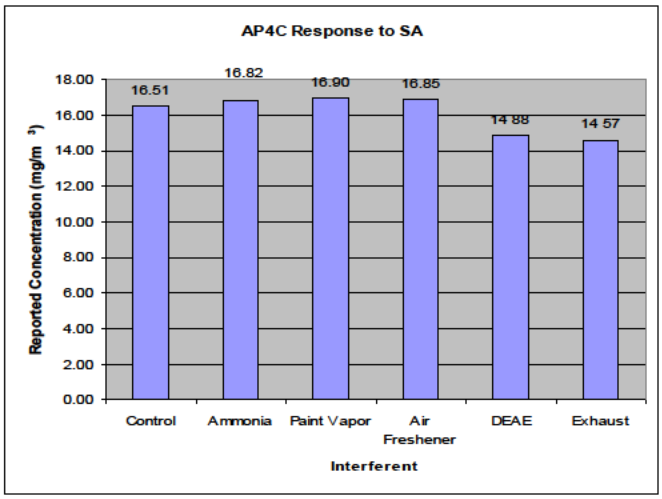
presence of the ammonia. This high concentration is not seen for the other chemicals as the data shown is reported from the respective channels that each agent is detected (phosphorus for GB, VX; Sulfur for HD, etc.).

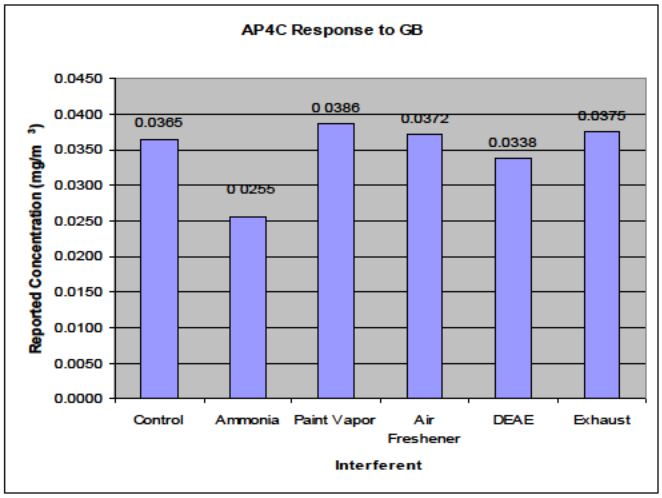
Figure B.6 – Effect of Interferents on Reported Concentrations

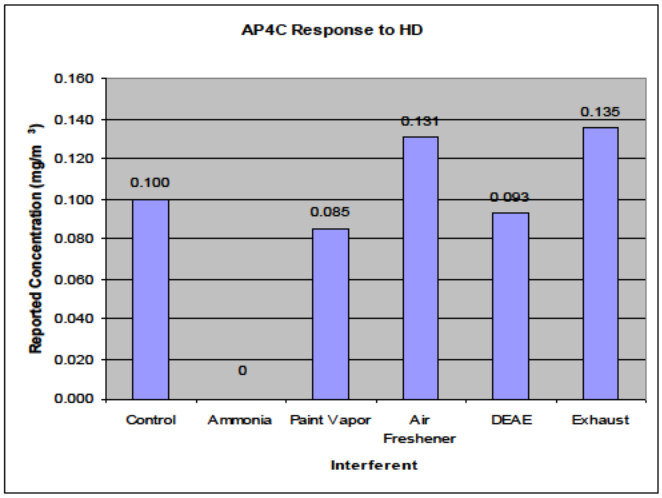


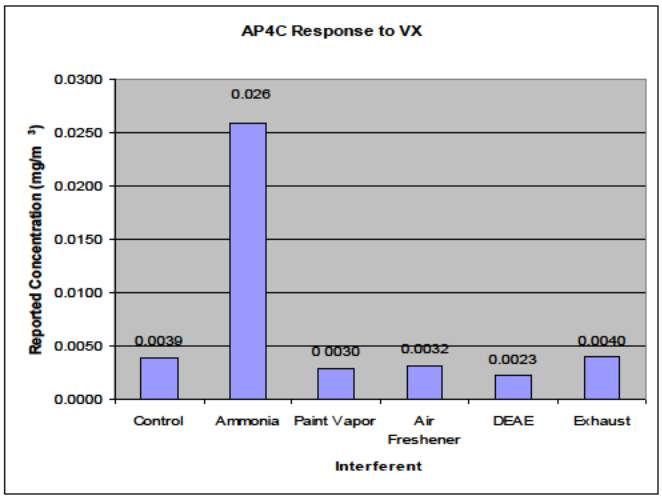









AP4C Response to HD
Reported Concentration (mg/m ³)
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
0.100
0
0.085
0.131
0.093
0.135
Control
Ammonia
Paint Vapor
Air Freshener
DEAE
Exhaust
Interferent


AP4C Response to VX
Reported Concentration (mg/m ³)
0.0300
0.0250
0.0200
0.0150
0.0100
0.0050
0.0000
0.0039
0.026
0 0030
0.0032
0.0023
0.0040
Control
Ammonia
Paint Vapor
Air Freshener
DEAE
Exhaust
Interferent

APPENDIX C: Data

Table C.1 – Response and Recovery Time – CK

Chemical	Challenge Concentration (mg/m^3)	Temp (^oC)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
CK	50.0	21.3	49.2	HNO	00:18	11.82	00:13
	50.0	21.4	48.6	HNO	00:15	12.39	00:12
	50.0	21.5	49.1	HNO	00:13	11.71	00:14
	50.0	21.6	52.7	HNO	00:13	12.60	00:14
	50.0	21.7	49.8	HNO	00:14	12.80	00:13
				mean	00:15	12.26	00:13
				std	2.1	0.4796	0.84
				rsd	14	3.911	6.3
CK	50.0	21.8	14.7	HNO	00:11	13.17	00:13
	50.0	21.9	14.2	HNO	00:13	13.07	00:13
	50.0	21.9	14.0	HNO	00:14	13.76	00:14
	50.0	21.9	13.8	HNO	00:13	13.36	00:15
	50.0	21.9	13.7	HNO	00:14	12.79	00:14
				mean	00:13	13.23	00:14
				std	1.2	0.3608	0.84
				rsd	9.4	2.727	6.1
CK	50.0	22.1	80.3	HNO	00:13	10.72	00:14
	50.0	22.1	80.4	HNO	00:16	10.96	00:13
	50.0	22.1	80.3	HNO	00:15	10.69	00:12
	50.0	22.1	80.4	HNO	00:14	10.89	00:13
	50.0	22.0	80.5	HNO	00:14	10.72	00:14
				mean	14	10.80	00:13
				std	1.1	0.1210	0.84
				rsd	7.9	1.120	6.3
CK	50.0	6.6	46.2	HNO	00:16	11.50	00:13
	50.0	7.1	48.4	HNO	00:16	12.04	00:13
	50.0	7.4	47.2	HNO	00:13	12.20	00:15
	50.0	7.5	47.1	HNO	00:15	12.06	00:15
	50.0	7.5	47.0	HNO	00:14	12.30	00:15
				mean	00:15	12.02	00:14
				std	1.3	0.3095	1.1
				rsd	8.8	2.575	7.7
CK	50.0	34.9	48.5	HNO	00:19	6.96	00:09
	50.0	35.1	47.8	HNO	00:22	6.79	00:09
	50.0	35.4	48.4	HNO	00:21	6.69	00:10
	50.0	35.6	47.7	HNO	00:22	6.51	00:07
	50.0	35.8	47.0	HNO	00:27	6.35	00:08
				mean	00:22	6.66	00:09
				std	2.9	0.2379	1.1
				rsd	13	3.572	13.3
CK	50.0	35.4	79.3	HNO	00:14	10.99	00:13
	50.0	35.4	79.4	HNO	00:13	11.28	00:13
	50.0	35.4	77.8	HNO	00:13	11.54	00:13
	50.0	35.4	77.7	HNO	00:12	11.78	00:14
	50.0	35.5	79.3	HNO	00:13	11.53	00:15
				mean	00:13	11.42	00:14
				std	0.71	0.3002	0.89
				rsd	5.4	2.628	6.6

Table C.2 – High/Low Concentration Tests – CK

Chemical	Challenge Concentration (mg/m^3)	Temp (°C)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
CK	50.0	22.6	49.0	HNO	00:16	10.15	00:13
	50.0	22.6	49.8	HNO	00:14	9.83	00:11
	50.0	22.7	50.3	HNO	00:16	10.03	00:08
	50.0	22.7	49.6	HNO	00:15	10.80	00:09
	50.0	22.8	49.4	HNO	00:15	10.80	00:10
CK	50.0	22.0	49.2	HNO	00:14	10.91	00:14
	0.6	22.1	49.8			-9.23	
	50.0	22.1	49.6	HNO	00:15	11.24	00:14
	0.6	22.0	49.8			-9.11	
	50.0	22.0	49.7	HNO	00:15	11.08	00:11
	0.6	22.0	49.7			-9.44	
	50.0	22.0	49.7	HNO	00:16	10.93	00:10
	0.6	22.0	49.8			-9.34	
	50.0	22.0	49.7	HNO	00:16	10.76	00:10
	0.6	22.0	49.8			-9.54	

Table C.3 – Response and Recovery Time – AC

Chemical	Challenge Concentration (mg/m^3)	Temp (°C)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
AC	55.3	23.1	47.6	HNO	00:09	36.58	00:18
	55.3	23.0	47.6	HNO	00:09	38.84	00:18
	55.3	23.0	47.6	HNO	00:08	36.38	00:17
	55.3	23.0	47.9	HNO	00:09	36.10	00:17
	55.3	23.0	48.1	HNO	00:08	36.05	00:19
				mean	00:09	36.79	00:18
				std	0.5	1.166	0.84
				rsd	6	3.169	4.7
AC	55.3	22.9	80.0	HNO	00:09	36.35	00:17
	55.3	22.9	79.6	HNO	00:08	36.18	00:18
	55.3	22.8	80.1	HNO	00:09	36.48	00:18
	55.3	22.8	80.1	HNO	00:07	36.43	00:16
	55.3	22.8	81.2	HNO	00:08	35.80	00:17
				mean	00:08	36.25	00:17
				std	0.8	0.2751	0.84
				rsd	10	0.7589	4.9
AC	55.3	21.9	9.3	HNO	00:06	44.49	00:25
	55.3	22.3	9.3	HNO	00:07	44.36	00:27
	55.3	22.7	8.8	HNO	00:06	43.76	00:25
	55.3	22.8	8.5	HNO	00:05	44.06	00:26
	55.3	22.8	8.5	HNO	00:06	43.71	00:27
				mean	00:06	44.08	00:26
				std	0.7	0.3486	1.0
				rsd	12	0.791	3.8
AC	55.3	5.1	49.9	HNO	00:05	43.70	00:27
	55.3	5.1	49.1	HNO	00:08	43.81	00:27
	55.3	5.1	49.2	HNO	00:06	43.73	00:28
	55.3	5.1	49.0	HNO	00:07	44.59	00:27
	55.3	5.1	49.0	HNO	00:06	44.65	00:29
				mean	00:06	44.10	00:28
				std	1	0.4805	0.89
				rsd	18	1.090	3.2
AC	55.3	34.8	48.9	HNO	00:09	36.59	00:23
	55.3	34.8	47.8	HNO	00:07	37.33	00:24
	55.3	34.8	50.0	HNO	00:07	37.28	00:22
	55.3	34.8	49.7	HNO	00:08	37.13	00:22
	55.3	34.8	49.8	HNO	00:11	37.51	00:21
				mean	00:08	37.17	00:22
				std	2	0.3505	1.1
				rsd	20	0.9429	5.1
AC	55.3	35.0	79.1	HNO	00:06	33.61	00:20
	55.3	34.9	80.1	HNO	00:09	33.67	00:20
	55.3	34.8	80.9	HNO	00:09	33.79	00:21
	55.3	34.8	81.1	HNO	00:08	34.00	00:21
	55.3	34.8	81.2	HNO	00:09	34.18	00:19
				mean	00:08	33.85	00:20
				std	1	0.2372	0.8367
				rsd	15.9	0.701	4.1

Table C.4 – High/Low Concentration Tests – AC

Chemical	Challenge Concentration (mg/m^3)	Temp (°C)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
AC	55.3	22.7	49.6	HNO	00:06	40.11	00:26
	55.3	22.8	50.1	HNO	00:07	39.87	00:25
	55.3	22.8	49.9	HNO	00:07	40.02	00:23
	55.3	22.9	49.9	HNO	00:07	39.83	00:23
	55.3	22.8	49.9	HNO	00:07	39.76	00:23
AC	55.3	22.6	49.4	HNO	00:07	41.58	
	11.1	22.6	49.4	HNO		5.79	
	55.3	22.6	49.6	HNO		41.76	
	11.1	22.7	49.4	HNO		5.39	
	55.3	22.7	49.1	HNO		41.69	
	11.1	22.7	49.1	HNO		5.32	
	55.3	22.7	49.2	HNO		41.94	
	11.1	22.7	49.2	HNO		5.51	
	55.3	22.8	49.1	HNO		41.83	
	11.1	22.7	49.0	HNO		5.78	00:07

Table C.5 – Response and Recovery Time – SA

Chemical	Challenge Concentration (mg/m^3)	Temp (°C)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
SA	10.82	21.6	49.9	Arsenic	00:07	17.08	01:16
	10.82	21.6	49.8	Arsenic	00:06	18.09	01:12
	10.82	21.6	49.9	Arsenic	00:06	17.07	01:11
	9.56	21.6	49.8	Arsenic	00:06	15.97	00:56
	9.56	21.7	49.9	Arsenic	00:06	16.29	01:01
				mean	00:06	16.90	01:07
				std	0	0.8238	8.3
				rsd	7	4.874	12
SA	9.56	21.6	20.4	Arsenic	00:05	16.34	01:09
	9.56	21.6	20.2	Arsenic	00:05	16.81	01:23
	9.56	21.6	20.1	Arsenic	00:05	16.86	01:17
	9.56	21.6	20.1	Arsenic	00:06	16.99	01:21
	9.56	21.6	20.1	Arsenic	00:06	17.10	01:13
				mean	00:05	16.82	01:17
				std	1	0.2913	5.7
				rsd	10	1.732	7.5
SA	9.56	21.7	75.1	Arsenic	00:07	16.27	01:18
	9.56	21.7	77.2	Arsenic	00:06	16.34	01:14
	9.56	21.7	77.0	Arsenic	00:06	16.30	01:24
	9.56	21.7	77.1	Arsenic	00:04	16.42	01:02
	9.56	21.7	77.2	Arsenic	00:04	16.44	00:53
				mean	00:05	16.35	01:10
				std	1	0.0740	13
				rsd	25	0.4527	18
SA	9.56	5.3	51.5	Arsenic	00:06	16:94	03:03
	9.56	5.0	47.1	Arsenic	00:05	17:59	03:39
	9.56	4.9	48.7	Arsenic	00:08	17:61	03:59
	9.56	4.8	48.9	Arsenic	00:04	15:16	02:20
	9.56	4.8	48.3	Arsenic	00:05	15:25	02:42
				mean	00:06	16.51	03:09
				std	2	1.222	40.5
				rsd	27	7.400	21.5
SA	9.56	34.2	45.2	Arsenic	00:05	14.55	01:54
	9.56	34.7	48.0	Arsenic	00:05	14.77	01:49
	9.56	34.8	48.1	Arsenic	00:04	14.85	02:10
	9.56	35.0	47.5	Arsenic	00:04	15.11	02:24
	9.56	35.0	50.8	Arsenic	00:05	15.13	02:28
				mean	00:05	14.88	02:09
				std	1	0.2436	17.4
				rsd	12	1.6366	13.5
SA	9.56	36.0	75.0	Arsenic	00:03	14.59	03:37
	9.56	36.5	75.1	Arsenic	00:03	14.60	04:55
	9.56	36.7	76.0	Arsenic	00:05	14.63	04:45
	9.56	36.8	76.4	Arsenic	00:02	14.52	02:47
	9.56	36.9	76.4	Arsenic	00:04	14.49	02:22
				mean	00:03	14.57	03:41
				std	1	0.0586	68.5
				rsd	34	0.4021	30.9

Table C.6 – High/Low Concentration Tests – SA

Chemical	Challenge Concentration (mg/m^3)	Temp (^oC)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
SA	9.56	22.1	51.0	Arsenic	00:08	9.33	00:50
	9.56	22.2	50.5	Arsenic	00:05	11.36	00:59
	9.56	22.1	51.0	Arsenic	00:05	13.61	01:02
	9.56	22.2	51.0	Arsenic	00:06	14.74	01:03
	9.56	22.2	51.0	Arsenic	00:05	15.01	01:02
SA	9.56	22.2	50.3	Arsenic	00:05	15.20	04:40
	0.2	22.2	50.9			0.77	
	9.56	22.2	50.7	Arsenic	00:00[b]	15.62	03:30
	0.2	22.2	50.9			0.74	
	9.56	22.2	50.8	Arsenic	00:00[b]	15.78	00:00[a]
	0.2	22.2	51.0			0.66	
	9.56	22.2	50.8	Arsenic	00:00[b]	15.88	00:00[a]
	0.2	22.2	50.9			0.69	
	9.56	22.2	50.7	Arsenic	00:00[b]	16.04	00:14
	0.2	22.2	50.8			0.74	
		22.1	51.0				

a – Alarm already off at challenge termination

b – Alarm already on at challenge start

Table C.7 – Response and Recovery Time – GB

Chemical	Challenge Concentration (mg/m^3)	Temp (^oC)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
GB	0.116	21.7	49.1	Phosphorus	00:10	0.0244	00:52
	0.116	21.7	49.0	Phosphorus	00:10	0.0363	02:01
	0.119	21.8	49.0	Phosphorus	00:08	0.0406	02:46
	0.117	21.7	49.1	Phosphorus	00:08	0.0402	02:41
	0.115	21.8	49.1	Phosphorus	00:05	0.0408	03:57
				mean	00:08	0.0365	02:27
				std	2	0.0070	68
				rsd	25	19.17	46
GB	0.117	21.7	20.3	Phosphorus	00:05	0.0440	04:29
	0.111	21.8	20.2	Phosphorus	00:05	0.0418	05:04
	0.083	21.7	20.3	Phosphorus	00:05	0.0329	03:20
	0.103	21.7	20.3	Phosphorus	00:06	0.0389	03:33
	0.108	21.8	20.3	Phosphorus	00:05	0.0406	03:35
				mean	00:05	0.0396	04:00
				std	0	0.0042	44.4
				rsd	9	10.60	18.5
GB	0.105	23.3	76.2	Phosphorus	00:09	0.0377	02:36
	0.112	23.3	76.2	Phosphorus	00:04	0.0422	03:03
	0.106	23.3	76.3	Phosphorus	00:08	0.0396	03:23
	0.082	23.3	76.4	Phosphorus	00:07	0.0347	03:05
	0.094	23.3	76.0	Phosphorus	00:09	0.0353	02:24
				mean	00:07	0.0379	03:54
				std	2	0.0031	23.8
				rsd	28	8.177	13.7
GB	0.0953	34.9	49.4	Phosphorus	00:01	0.0408	03:43
	0.109	34.8	47.7	Phosphorus	00:04	0.0476	03:55
	0.117	34.8	48.3	Phosphorus	00:05	0.0466	03:45
	0.110	34.8	49.1	Phosphorus	00:07	0.0436	03:21
	0.103	34.8	48.7	Phosphorus	00:07	0.0407	03:21
				mean	00:05	0.0439	03:35
				std	2	0.0032	15.0
				rsd	52	7.292	6.96
GB	0.118	34.9	79.2	Phosphorus	00:09	0.0568	02:47
	0.102	34.9	79.4	Phosphorus	00:04	0.0366	03:54
	0.0904	34.9	79.3	Phosphorus	00:04	0.0379	03:23
	0.101	34.9	77.1	Phosphorus	00:05	0.0400	04:35
	0.0989	34.9	78.6	Phosphorus	00:04	0.0392	03:54
				mean	00:05	0.0421	03:43
				std	2	0.0083	40.3
				rsd	42	19.76	18.1
GB	0.102	5.2	47.7	Phosphorus	00:09	0.0339	02:54
	0.0973	5.1	50.0	Phosphorus	00:09	0.0338	03:12
	0.0981	5.1	50.1	Phosphorus	00:08	0.0341	03:06
	0.0999	5.0	48.8	Phosphorus	00:08	0.0345	02:45
	0.115	5.0	49.3	Phosphorus	00:09	0.0411	03:34
				mean	00:09	0.0355	03:06
				std	1	0.0032	18.7
				rsd	6	8.89	10.1

Table C.8 – High/Low Concentration Tests – GB

Chemical	Challenge Concentration (mg/m^3)	Temp (°C)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
GB	0.0973	22.5	50.7	Phosphorus	00:10	0.0342	01:47
	0.0913	22.5	50.7	Phosphorus	00:07	0.0291	02:06
	0.103	22.5	50.8	Phosphorus	00:07	0.0345	02:22
	0.0988	22.5	50.7	Phosphorus	00:05	0.0260	02:39
GB	0.0994	22.5	50.7	Phosphorus	00:04	0.0341	02:01
	0.00003*	22.5	50.7			0.0022	
	0.0886	22.5	50.7	Phosphorus	00:09	0.0364	02:51
	0.00003*	22.5	50.7			0.0025	
	0.0926	22.5	50.8	Phosphorus	00:08	0.0379	03:14
	0.00003*	22.5	50.7			0.0027	
	0.0945	22.5	50.8	Phosphorus	00:09	0.0391	02:50
	0.00003*	22.5	50.8			0.0027	
	0.0946	22.5	50.8	Phosphorus	00:08	0.0401	02:50
	0.00003*	22.5	50.7			0.0033	

* - concentration not actively measured

Table C.9 – Response and Recovery Time – HD

Chemical	Challenge Concentration (mg/m^3)	Temp (ºC)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
HD	0.683	22.4	49.9	Sulfur	00:46	0.097	00:10
	0.691	22.4	50.0	Sulfur	00:57	0.100	00:03
	0.701	22.4	49.5	Sulfur	01:03	0.108	00:14
	0.726	22.5	49.9	Sulfur	00:46	0.108	00:11
	0.717	22.5	50.0	Sulfur	00:41	0.100	00:05
				mean	00:51	0.103	00:09
				std	9.1	0.0051	5
				rsd	18	4.95	52
HD	0.702	22.4	16.9	Sulfur	01:19	0.099	00:15
	0.696	22.5	16.7	Sulfur	01:39	0.087	00:00[a]
	0.705	22.5	16.7	Sulfur	01:05	0.092	00:00[a]
	0.740	22.5	16.8	Sulfur	00:47	0.096	00:12
	0.759	22.5	16.8	Sulfur	00:50	0.102	00:00[a]
				mean	01:08	0.095	-
				std	22	0.0059	-
				rsd	32	6.19	-
HD	0.648	22.6	80.4	Sulfur	00:42	0.083	00:00[a]
	0.694	22.6	81.1	Sulfur	00:47	0.089	00:00[a]
	0.694	22.6	80.8	Sulfur	01:48	0.090	00:04
	0.606	22.7	81.0	Sulfur	01:32	0.078	00:00[a]
	0.705	22.6	81.1	Sulfur	01:16	0.097	00:00[a]
				mean	01:13	0.087	-
				std	28	0.0072	-
				rsd	39	8.27	-
HD	0.597	35.4	76.4	Sulfur	00:36	0.127	00:15
	0.681	35.4	75.6	Sulfur	00:33	0.136	00:19
	0.744	35.4	80.0	Sulfur	00:34	0.135	00:16
	0.761	35.4	79.3	Sulfur	00:33	0.124	00:12
	0.784	35.4	79.4	Sulfur	00:46	0.119	00:15
				mean	00:36	0.128	00:15
				std	5.5	0.0073	2.5
				rsd	15	5.66	16
HD	0.741	35.3	48.7	Sulfur	01:13	0.090	00:00[a]
	0.738	35.3	51.6	Sulfur	00:54	0.102	00:02
	0.720	35.3	50.7	Sulfur	01:51	0.079	00:05
	0.732	35.4	50.4	Sulfur	00:55	0.094	00:01
	0.747	35.3	50.2	Sulfur	01:04	0.095	00:03
				mean	01:11	0.092	-
				std	23	0.0085	-
				rsd	33	9.19	-

a – Alarm already off at challenge termination

Table C.10 – High/Low Concentration Tests – HD

Chemical	Challenge Concentration (mg/m^3)	Temp (°C)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
HD	0.666	22.4	50.9	Sulfur	00:32	0.145	00:14
	0.734	22.4	50.7	Sulfur	00:31	0.157	00:15
	0.796	22.4	50.6	Sulfur	00:34	0.153	00:17
	0.790	22.4	50.7	Sulfur	00:31	0.133	00:15
HD	0.776	22.4	50.6	Sulfur	00:33	0.132	00:13
	0.003*	22.4	50.5			-0.012	
	0.600	22.4	50.5	Sulfur	00:29	0.144	00:13
	0.003*	22.4	50.4			-0.008	
	0.634	22.4	50.4	Sulfur	00:28	0.165	00:20
	0.003*	22.4	50.3			-0.019	
	0.632	22.4	50.3	Sulfur	00:27	0.168	00:14
	0.003*	22.4	50.3			-0.018	
	0.653	22.4	50.3	Sulfur	00:28	0.162	00:10
	0.003*	22.4	50.2			-0.006	

a – Alarm already off at challenge termination

* - concentration not actively measured

Table C.11 – Response and Recovery Time – VX

Chemical	Challenge Concentration (mg/m^3)	Temp (°C)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
VX	0.0177	22.2	49.9	Phosphorus	00:37	0.0036	00:25
	0.0192	22.2	49.9	Phosphorus	00:30	0.0040	00:25
	0.0196	22.2	49.8	Phosphorus	00:27	0.0041	00:26
	0.0199	22.2	49.8	Phosphorus	00:24	0.0041	00:29
	0.0196	22.2	49.8	Phosphorus	00:29	0.0039	00:30
				mean	00:29	0.0039	00:27
				std	4.8	0.00021	2.3
				rsd	16	5.3	8.7
VX	0.0197	22.2	17.8	Phosphorus	00:27	0.0040	00:25
	0.0173	22.2	17.5	Phosphorus	00:32	0.0041	00:33
	0.0163	22.3	17.2	Phosphorus	00:39	0.0036	00:43
	0.0165	22.3	17.1	Phosphorus	00:32	0.0038	00:31
	0.0167	22.3	17.0	Phosphorus	00:40	0.0039	00:24
				mean	00:34	0.0039	00:31
				std	5.4	0.00019	7.6
				rsd	16	5.0	24
VX	0.0187	22.4	81.4	Phosphorus	00:30	0.0026	00:08
	0.0173	22.4	81.8	Phosphorus	01:03	0.0027	00:19
	0.0176	22.3	81.8	Phosphorus	00:44	0.0028	00:03
	0.0189	22.3	82.0	Phosphorus	00:29	0.0032	00:15
	0.0195	22.4	81.9	Phosphorus	00:53	0.0030	00:16
				mean	00:44	0.0029	00:12
				std	15	0.00024	6.5
				rsd	34	8.4	54
VX	0.0166	34.6	53.0	Phosphorus	00:39	0.0036	00:35
	0.0165	35.7	53.0	Phosphorus	00:30	0.0038	00:26
	0.0162	35.8	52.3	Phosphorus	00:35	0.0039	00:28
	0.0184	35.9	53.1	Phosphorus	00:31	0.0046	00:54
	0.0187	35.9	53.4	Phosphorus	00:21	0.0049	00:40
				mean	00:31	0.0042	00:37
				std	6.7	0.00056	11
				rsd	22	13	31
VX	0.0184	35.5	79.1	Phosphorus	00:22	0.0075	00:57
	0.0219	35.5	79.1	Phosphorus	00:20	0.0083	01:01
	0.0230	35.5	79.9	Phosphorus	00:17	0.0078	01:16
	0.0216	35.5	79.9	Phosphorus	00:12	0.0076	00:58
	0.0158	35.5	80.1	Phosphorus	00:23	0.0075	00:44
				mean	00:19	0.0077	00:59
				std	4.4	0.00034	11
				rsd	24	4.3	19
VX	0.0181	5.0	50.3	Phosphorus	01:10	0.0012	00:00[a]
	0.0160	5.0	50.9	Phosphorus	01:19	0.0011	00:00[a]
	0.0167	5.0	50.8	Phosphorus	01:12	0.0016	00:03
	0.0166	5.1	50.9	Phosphorus	01:36	0.0016	00:02

	0.0164	5.0	50.9	Phosphorus	01:25	0.0014	00:00[a]
				mean	01:20	0.0014	-
				std	11	0.00023	-
				rsd	13	17	-

a – Alarm already off at challenge termination

Table C.12 – High/Low Concentration Tests – VX

Chemical	Challenge Concentration (mg/m^3)	Temp (°C)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
VX	0.0232	22.0	51.5	Phosphorus	01:47	0.0015	00:00[a]
	0.0183	22.1	51.6	Phosphorus	00:50	0.0022	00:17
	0.0190	22.1	51.1	Phosphorus	00:43	0.0023	00:19
	0.0202	22.1	51.2	Phosphorus	00:49	0.0028	00:06
VX	0.0211	22.2	51.2	Phosphorus	00:42	0.0029	00:20
	0.0128	22.1	50.8	Phosphorus		0.0002	
	0.0224	22.1	50.7	Phosphorus	00:50	0.0030	00:21
	0.0128	22.1	50.7	Phosphorus		0.0004	
	0.0214	22.1	50.8	Phosphorus	00:46	0.0027	00:19
	0.0132	22.1	50.8	Phosphorus		0.0002	
	0.0214	22.1	50.7	Phosphorus	00:31	0.0032	00:21
	0.0133	22.1	50.7	Phosphorus		0.0003	
	0.0219	22.2	51.2	Phosphorus	00:46	0.0033	00:31
	0.0136	22.1	50.7	Phosphorus		0.0005	

a – alarm already off at challenge termination.

Table C.13 – Response Thresholds

Chemical	Challenge Concentration (mg/m^3)	Temp (ºC)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
CK	10.0	22.1	47.5	No alarm	-	-2.77	-
	20.0	22.1	47.6	No alarm	-	0.429	-
	25.0	22.1	47.5	No alarm	-	1.58	-
	30.0	22.1	47.5	HNO	0:45	3.49	0:00[a]
AC	10	22.8	49.5	HNO	00:14	3.94	00:06
	5	22.9	49.4	No alarm	-	0.92	-
SA	0.2	22.3	50.5	Arsenic	00:25	0.582	00:06
	0.1	22.2	49.5	Arsenic	00:26	0.420	00:00[a]
	0.05	22.2	49.5	Arsenic	04:22	0.290	00:00[a]
	0.025	22.2	50.7	No alarm	-	0.231	-
GB	0.0107	22.5	50.8	Phosphorus	01:55	0.0013	00:00[a]
	0.00556	22.6	50.7	No alarm	-	-	-
HD	0.581	22.4	50.0	Sulfur	00:39	0.085	00:00[a]
	0.476	22.2	50.0	Sulfur	04:27	0.053	00:00[a]
	0.386	22.5	49.9	No alarm	-	-	-
VX	0.00904	21.9	50.5	Phosphorus	02:46	0.0011	00:00[a]
	0.00621	22.0	50.4	No alarm	-	-	-
L	3.35	22.0	50.5	Arsenic	00:45	0.51	00:20
	2.36	22.1	50.2	Arsenic	00:44	0.47	00:00[a]
	2.12	22.0	49.9	Arsenic	01:48	0.37	00:04
	1.94	22.1	50.0	Arsenic	04:58	0.30	00:00[a]
	1.54	22.0	49.9	Arsenic	04:29	0.30	00:00[a]
	1.35	22.0	50.0	Arsenic	04:59	0.29	00:00[a]
	1.19	22.0	49.9	No alarm	-	-	-

a – alarm already off at challenge termination.

Red shading indicates alarm at this concentration; Blue shading indicates no alarm at this concentration

Table C.14 – Interferent Tests – Baseline

Chemical	Challenge Concentration (mg/m^3)	Interferent	Temp (°C)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
None		Ammonia	23.1	55.1	HNO	00:06	115.99	00:27
		Ammonia	23.1	50.6	HNO	00:06	125.94	00:27
		Ammonia	23.1	51.2	HNO	00:06	128.41	00:27
		Ammonia	23.1	50.7	HNO	00:06	134.40	00:28
		Ammonia	23.1	55.1	HNO	00:05	116.60	00:30
					mean	00:06	124.27	00:28
					std	0.4	7.9046	1.3
					rsd	8	6.3610	4.7
None		Paint Vapor	23.1	51.6	No alarm	-	-	-
		Paint Vapor	23.1	50.7	No alarm	-	-	-
		Paint Vapor	23.0	50.6	No alarm	-	-	-
		Paint Vapor	23.0	50.5	No alarm	-	-	-
		Paint Vapor	22.9	51.1	No alarm	-	-	-
None		Air Freshener	21.4	49.9	No alarm	-	-	-
		Air Freshener	21.7	49.1	No alarm	-	-	-
		Air Freshener	21.9	49.2	No alarm	-	-	-
		Air Freshener	22.1	49.1	No alarm	-	-	-
		Air Freshener	22.1	49.5	No alarm	-	-	-
None		DEAE	22.9	49.8	HNO	00:19	10.03	00:11
		DEAE	22.9	49.8	HNO	00:18	9.86	00:10
		DEAE	22.9	49.7	HNO	00:19	9.74	00:11
		DEAE	22.9	49.7	HNO	00:21	9.62	00:10
		DEAE	22.9	49.8	HNO	00:18	9.82	00:11
					mean	00:19	9.81	00:11
					std	1.2	0.152	0.55
					rsd	6.4	1.54	5.2
None		Exhaust	22.5	48.7	No alarm	-	-	-
		Exhaust	22.5	49.2	No alarm	-	-	-
		Exhaust	22.5	48.5	No alarm	-	-	-
		Exhaust	22.5	49.3	No alarm	-	-	-
		Exhaust	22.5	48.5	No alarm	-	-	-

Table C.15 – Interferent Tests – CK

Chemical	Challenge Concentration (mg/m^3)	Interferent	Temp (°C)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
CK	50.0	Ammonia	23.1	51.5	HNO	00:05	110.25	00:28
	50.0	Ammonia	23.1	51.3	HNO	00:06	102.82	00:27
	50.0	Ammonia	23.1	51.3	HNO	00:08	96.37	00:24
	50.0	Ammonia	23.0	51.7	HNO	00:06	82.86	00:25
	50.0	Ammonia	23.0	51.0	HNO	00:07	76.85	00:23
					mean	00:06	93.83	00:25
					std	1	13.83	2.1
					rsd	18	14.74	8.2
CK	50.0	Paint Vapor	22.9	51.7	HNO	00:16	10.63	00:12
	50.0	Paint Vapor	22.9	51.6	HNO	00:16	10.48	00:10
	50.0	Paint Vapor	22.9	51.8	HNO	00:15	10.36	00:09
	50.0	Paint Vapor	22.9	51.8	HNO	00:14	10.25	00:10
	50.0	Paint Vapor	22.9	50.4	HNO	00:15	10.00	00:09
					mean	00:15	10.34	00:10
					std	0.84	0.2386	1
					rsd	5.5	2.307	12
CK	50.0	Air Freshener	22.2	49.3	HNO	00:14	12.91	00:14
	50.0	Air Freshener	22.3	48.7	HNO	00:15	13.03	00:13
	50.0	Air Freshener	23.3	48.3	HNO	00:14	13.23	00:13
	50.0	Air Freshener	22.4	49.2	HNO	00:13	13.38	00:14
	50.0	Air Freshener	22.4	49.0	HNO	00:14	13.22	00:13
					mean	00:14	13.15	00:13
					std	0.71	0.1845	0.55
					rsd	5.1	1.402	4.1
CK	50.0	DEAE	22.8	49.7	HNO	00:11	27.00	00:15
	50.0	DEAE	22.8	49.5	HNO	00:12	26.77	00:17
	50.0	DEAE	22.8	49.8	HNO	00:10	27.24	00:17
	50.0	DEAE	22.9	49.6	HNO	00:12	27.17	00:18
	50.0	DEAE	22.8	49.5	HNO	00:11	27.15	00:15
					mean	00:11	27.07	00:16
					std	0.84	0.1872	1.3
					rsd	7.5	0.6915	8.2
CK	50.0	Exhaust	22.6	49.1	HNO	00:15	12.00	00:09
	50.0	Exhaust	22.6	49.1	HNO	00:13	11.90	00:09
	50.0	Exhaust	22.7	49.1	HNO	00:15	12.16	00:11
	50.0	Exhaust	22.7	49.0	HNO	00:16	12.22	00:10
	50.0	Exhaust	22.7	48.8	HNO	00:12	12.81	00:10
					mean	00:14	12.22	00:10
					std	1.6	0.3544	0.84
					rsd	12	2.901	8.5

Table C.16 – Interferent Tests – AC

Chemical	Challenge Concentration (mg/m^3)	Interferent	Temp (°C)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
AC	55.3	Ammonia	22.2	51.2	HNO	00:06	129.56	00:40
	55.3	Ammonia	22.2	51.2	HNO	00:04	127.85	00:36
	55.3	Ammonia	22.3	51.3	HNO	00:05	129.07	00:37
	55.3	Ammonia	22.2	51.3	HNO	00:05	144.17	00:42
	55.3	Ammonia	22.3	51.1	HNO	00:05	132.39	00:38
					mean	00:05	132.61	00:39
					std	0.7	6.6741	2.4
					rsd	14	5.0329	6.2
AC	55.3	Paint Vapor	22.2	51.1	HNO	00:07	39.78	00:27
	55.3	Paint Vapor	22.2	50.3	HNO	00:07	39.63	00:25
	55.3	Paint Vapor	22.3	50.3	HNO	00:08	39.24	00:26
	55.3	Paint Vapor	22.3	50.1	HNO	00:07	39.49	00:24
	55.3	Paint Vapor	22.3	50.2	HNO	00:06	39.29	00:23
					mean	00:07	39.49	00:25
					std	0.7	0.2270	1.6
					rsd	10	0.5749	6.3
AC	55.3	Air Freshener	22.2	51.7	HNO	00:06	40.16	00:25
	55.3	Air Freshener	22.2	51.7	HNO	00:07	39.24	00:26
	55.3	Air Freshener	22.2	51.4	HNO	00:06	39.86	00:27
	55.3	Air Freshener	22.2	51.3	HNO	00:07	39.38	00:26
	55.3	Air Freshener	22.2	51.4	HNO	00:06	39.21	00:25
					mean	00:06	39.57	00:26
					std	0.5	0.4204	0.84
					rsd	9	1.062	3.2
AC	55.3	DEAE	22.8	49.6	HNO	00:08	52.48	00:29
	55.3	DEAE	22.8	49.1	HNO	00:06	53.11	00:30
	55.3	DEAE	22.9	49.5	HNO	00:07	53.51	00:30
	55.3	DEAE	22.8	49.5	HNO	00:07	53.20	00:30
	55.3	DEAE	22.8	49.5	HNO	00:09	53.66	00:30
					mean	00:07	53.19	00:30
					std	1	0.4566	0.45
					rsd	15	0.8584	1.5
AC	55.3	Exhaust	22.6	52.5	HNO	00:07	41.90	00:25
	55.3	Exhaust	22.6	52.2	HNO	00:07	41.22	00:26
	55.3	Exhaust	22.4	52.9	HNO	00:08	41.00	00:24
	55.3	Exhaust	22.2	51.7	HNO	00:07	40.82	00:23
	55.3	Exhaust	22.2	51.5	HNO	00:07	40.56	00:24
					mean	00:07	41.10	00:24
					std	0	0.5085	1.1

					rsd	6	1.237	4.7

Table C.17 – Interferent Tests – SA

Chemical	Challenge Concentration (mg/m^3)	Interferent	Temp (ºC)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
SA	9.56	Ammonia	22.2	50.2	Arsenic	00:05	12.41	02:51
					HNO	00:07	45.09	00:29
	9.56	Ammonia	22.2	50.2	Arsenic	00:05	13.87	02:07
					HNO	00:10	11.53	00:14
	9.56	Ammonia	22.2	50.0	Arsenic	00:05	13.66	01:59
					HNO	00:12	18.02	00:14
	9.56	Ammonia	22.2	50.1	Arsenic	00:04	13.76	01:54
					HNO	00:14	14.32	00:11
	9.56	Ammonia	22.2	49.9	Arsenic	00:06	13.95	01:39
					HNO	00:17	10.62	00:14
					Arsenic mean	00:05	13.53	02:06
					Arsenic std	0.7	0.6356	27
					Arsenic rsd	14	4.698	22
					HNO mean	00:12	19.92	00:16
					HNO std	4	14.36	7.2
					HNO rsd	32	72.13	44
SA	9.56	Paint Vapor	22.2	50.1	Arsenic	00:06	15.65	00:55
	9.56	Paint Vapor	22.2	50.1	Arsenic	00:05	15.39	01:37
	9.56	Paint Vapor	22.2	50.1	Arsenic	00:05	15.22	01:29
	9.56	Paint Vapor	22.2	49.9	Arsenic	00:04	15.28	01:39
	9.56	Paint Vapor	22.2	50.1	Arsenic	00:03	15.28	01:32
					mean	00:05	15.36	01:26
					std	1	0.1713	18
					rsd	25	1.115	21
SA	9.56	Air Freshener	22.2	48.9	Arsenic	00:05	14.80	02:29
	9.56	Air Freshener	22.2	48.3	Arsenic	00:04	15.02	01:10
	9.56	Air Freshener	22.2	48.1	Arsenic	00:04	15.18	01:24
	9.56	Air Freshener	22.2	48.9	Arsenic	00:05	15.28	02:04
	9.56	Air Freshener	22.2	48.4	Arsenic	00:04	15.35	01:43
					mean	00:04	15.13	01:46
					std	0.5	0.2204	31
					rsd	12	1.457	30
SA	9.56	DEAE	22.2	49.8	Arsenic	00:05	15.03	01:14
	9.56	DEAE	22.2	49.8	Arsenic	00:06	14.22	03:12
					HNO	2:06	3.65	00:06
	9.56	DEAE	22.2	49.7	Arsenic	00:04	14.10	02:42
					HNO	00:43	4.28	00:03

	9.56	DEAE	22.2	49.5	Arsenic	00:04	14.12	03:10
					HNO	00:42	3.93	00:00[a]
	9.56	DEAE	22.2	49.1	Arsenic	00:05	14.18	03:11
					HNO	00:38	3.79	00:00[a]
					Arsenic mean	00:05	14.33	02:42
					Arsenic std	0.5	0.3942	51
					Arsenic rsd	12	2.751	31
					HNO mean	00:50	3.13	-
					HNO std	43	0.270	-
					HNO rsd	85	8.64	-
SA	9.56	Exhaust	21.8	50.1	Arsenic	00:05	14.04	01:29
	9.56	Exhaust	21.7	49.4	Arsenic	00:05	14.30	02:25
	9.56	Exhaust	21.8	49.3	Arsenic	00:05	14.23	03:19
	9.56	Exhaust	21.8	49.2	Arsenic	00:05	14.21	02:42
	9.56	Exhaust	21.7	49.1	Arsenic	00:03	14.34	03:03
					mean	00:05	14.22	02:36
					std	1	0.1155	42
					rsd	19	0.8117	27

a – Alarm already off at challenge termination

Table C.18 – Interferent Tests – GB

Chemical	Challenge Concentration (mg/m^3)	Interferent	Temp (ºC)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
GB	0.111	Ammonia	23.2	50.0	Phosphorus	00:05	0.0293	03:20
					HNO	00:09	40.00	00:26
	0.101	Ammonia	23.2	50.0	Phosphorus	00:06	0.0258	03:43
					HNO	00:07	46.59	00:32
	0.0962	Ammonia	23.3	50.0	Phosphorus	00:05	0.0256	03:36
					HNO	00:07	40.74	00:26
	0.0826	Ammonia	23.3	50.0	Phosphorus	00:07	0.0228	03:01
					HNO	00:10	36.55	00:28
	0.0874	Ammonia	23.3	50.0	Phosphorus	00:08	0.0241	03:13
					HNO	00:10	35.55	00:26
					P mean	00:06	0.0255	03:23
					P std	3	0.0106	84.1
					P rsd	45	41.7	41.5
					HNO mean	00:09	39.89	00:28
					HNO std	2	4.348	2.6
					HNO rsd	18	10.90	9.4
GB	0.102	Paint Vapor	23.3	49.9	Phosphorus	00:06	0.0380	03:36
	0.0998	Paint Vapor	23.3	50.2	Phosphorus	00:06	0.0383	03:39
	0.0871	Paint Vapor	23.3	50.1	Phosphorus	00:04	0.0382	02:47
	0.0990	Paint Vapor	23.3	50.1	Phosphorus	00:03	0.0391	03:51
	0.102	Paint Vapor	23.2	49.8	Phosphorus	00:04	0.0392	03:16
					mean	00:05	0.0386	03:26
					std	1	0.000550	25.1
					rsd	29	1.43	12.2
GB	0.0982	Air Freshener	23.3	48.1	Phosphorus	00:08	0.0355	03:41
	0.103	Air Freshener	23.3	50.1	Phosphorus	00:08	0.0378	03:09
	0.102	Air Freshener	23.3	50.3	Phosphorus	00:09	0.0376	03:28
	0.102	Air Freshener	23.3	49.5	Phosphorus	00:04	0.0377	03:17
	0.0911	Air Freshener	23.3	49.3	Phosphorus	00:06	0.0374	04:16
					mean	00:07	0.0372	03:34
					std	2	0.000962	26.3
					rsd	29	2.59	12.3
GB	0.0898	DEAE	23.3	49.9	Phosphorus	00:06	0.0313	04:20
					HNO	00:30	4.87	00:00[a]
	0.111	DEAE	21.7	46.8	Phosphorus	00:08	0.0322	02:53
					HNO	00:29	11.32	00:18

	0.103	DEAE	22.1	47.0	Phosphorus	00:06	0.0353	04:19
					HNO	00:27	10.05	00:18
	0.103	DEAE	22.0	47.8	Phosphorus	00:05	0.0348	04:30
					HNO	00:19	9.65	00:16
	0.103	DEAE	21.9	49.8	Phosphorus	00:05	0.0356	05:04
					HNO	00:18	9.68	00:14
					P mean	00:06	0.0338	04:13
					P std	1	0.00196	48.4
					P rsd	20	5.78	19.1
					HNO mean	00:25	9.11	-
					HNO std	5.7	2.47	-
					HNO rsd	23	27.1	-
GB	0.110	Exhaust	21.8	49.4	Phosphorus	00:09	0.0358	03:50
	0.114	Exhaust	21.8	48.2	Phosphorus	00:05	0.0339	04:11
	0.112	Exhaust	21.8	47.7	Phosphorus	00:03	0.0375	03:45
	0.112	Exhaust	21.8	47.3	Phosphorus	00:08	0.0393	03:45
	0.112	Exhaust	21.8	48.7	Phosphorus	00:05	0.0408	03:53
					mean	00:06	0.0375	03:53
					std	2	0.00274	10.7
					rsd	41	7.31	4.61

a – Alarm already off at challenge termination

Table C.19 – Interferent Tests – HD

Chemical	Challenge Concentration (mg/m^3)	Interferent	Temp (°C)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
HD	0.608	Ammonia	22.6	50.4	HNO	00:14	18.55	00:15
	0.761	Ammonia	22.6	50.3	HNO	00:13	17.15	00:18
	0.773	Ammonia	22.6	50.3	HNO	00:11	15.78	00:17
	0.795	Ammonia	22.6	50.3	HNO	00:12	14.01	00:14
	0.758	Ammonia	22.6	50.2	HNO	00:09	12.89	00:15
					mean	00:12	15.68	00:16
					std	2	2.290	1.6
					rsd	16	14.61	10
HD	0.582	Paint Vapor	22.6	48.9	Sulfur	00:34	0.086	00:00[a]
	0.582	Paint Vapor	22.6	47.8	Sulfur	01:42	0.079	00:08
	0.590	Paint Vapor	22.6	48.0	Sulfur	01:40	0.085	00:00[a]
	0.698	Paint Vapor	22.6	47.9	Sulfur	01:30	0.087	00:10
	0.728	Paint Vapor	22.6	47.3	Sulfur	01:54	0.090	00:05
					mean	01:28	0.085	-
					std	31	0.00404	-
					rsd	36	4.73	-
HD	0.742	Air Freshener	22.4	49.1	Sulfur	00:31	0.125	00:08
	0.703	Air Freshener	22.4	49.9	Sulfur	00:34	0.135	00:03
	0.689	Air Freshener	22.5	49.8	Sulfur	00:41	0.133	00:14
	0.698	Air Freshener	22.5	49.7	Sulfur	00:30	0.134	00:18
	0.710	Air Freshener	22.5	49.8	Sulfur	00:30	0.128	00:12
					mean	00:33	0.131	00:11
					std	4.7	0.00430	6
					rsd	14	3.28	52
HD	0.742	DEAE	22.6	47.3	Sulfur	00:38	0.091	00:00[a]
	0.610	DEAE	22.6	50.0	Sulfur	00:38	0.106	00:00[a]
	0.585	DEAE	22.6	50.5	Sulfur	00:46	0.094	00:00[a]
	0.764	DEAE	22.6	50.4	Sulfur	00:50	0.087	00:00[a]
	0.728	DEAE	22.6	49.9	Sulfur	01:53	0.088	00:00[a]
					mean	00:57	0.093	-
					std	32	0.0077	-

					rsd	56	8.2	-
HD	0.690	Exhaust	22.5	50.9	Sulfur	00:30	0.138	00:15
	0.711	Exhaust	22.5	50.8	Sulfur	00:31	0.137	00:13
	0.706	Exhaust	22.4	50.7	Sulfur	00:30	0.137	00:09
	0.682	Exhaust	22.5	50.5	Sulfur	00:31	0.125	00:13
	0.687	Exhaust	22.5	50.7	Sulfur	00:27	0.136	00:13
					mean	00:30	0.135	00:13
					std	1.6	0.00541	2
					rsd	5.5	4.02	17

a – Alarm already off at challenge termination

Table C.20 – Interferent Tests – VX

Chemical	Challenge Concentration (mg/m^3)	Interferent	Temp (°C)	RH (%)	Alarm? (Channel)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
VX	0.0187	Ammonia	21.9	50.2	Phosphorus	00:57	0.0025	00:23
					HNO	00:21	8.94	00:14
	0.0194	Ammonia	21.9	50.2	Phosphorus	01:09	0.0026	00:17
					HNO	00:20	8.15	00:19
	0.0195	Ammonia	21.9	50.2	Phosphorus	00:53	0.0026	00:05
					HNO	00:20	7.78	00:11
	0.0197	Ammonia	21.9	50.2	Phosphorus	00:25	0.0026	00:21
					HNO	00:22	7.24	00:12
	0.0196	Ammonia	21.9	50.2	Phosphorus	00:37	0.0028	00:16
					HNO	00:25	7.38	00:09
					P mean	00:48	0.0026	00:16
					P std	25	0.0011	9
					P rsd	52	41	56
					HNO mean	00:22	7.90	00:13
					HNO std	2.1	0.683	4
					HNO rsd	9.6	8.64	29
VX	0.0232	Paint Vapor	21.9	50.3	Phosphorus	00:37	0.0030	00:34
	0.0209	Paint Vapor	22.0	50.3	Phosphorus	00:29	0.0029	00:18
	0.0197	Paint Vapor	22.0	50.3	Phosphorus	00:29	0.0029	00:07
	0.0188	Paint Vapor	22.0	50.4	Phosphorus	00:38	0.0030	00:32
	0.0183	Paint Vapor	22.0	50.3	Phosphorus	00:42	0.0030	00:26
					mean	00:35	0.0030	00:23
					std	5.8	0.000055	11
					rsd	17	1.9	47
VX	0.0211	Air Freshener	21.9	50.3	Phosphorus	00:46	0.0033	00:11
	0.0212	Air Freshener	21.9	50.3	Phosphorus	00:30	0.0029	00:20
	0.0213	Air Freshener	21.9	50.3	Phosphorus	00:37	0.0032	00:17
	0.0211	Air Freshener	22.0	50.3	Phosphorus	00:43	0.0032	00:21
	0.0238	Air Freshener	22.0	50.3	Phosphorus	00:36	0.0032	00:27
					mean	00:38	0.0032	00:19
					std	6.3	0.00015	5.8
					rsd	16	4.8	30

VX	0.0235	DEAE	21.9	50.4	Phosphorus	00:39	0.0026	00:14
					HNO	00:15	10.14	00:15
	0.0232	DEAE	21.9	50.3	Phosphorus	00:43	0.0025	00:00[a]
					HNO	00:16	10.32	00:13
	0.0213	DEAE	21.9	50.4	Phosphorus	00:53	0.0022	00:12
					HNO	00:16	10.05	00:13
	0.0203	DEAE	21.9	50.2	Phosphorus	01:23	0.0021	00:00[a]
					HNO	00:16	10.34	00:14
	0.0179	DEAE	21.9	50.3	Phosphorus	00:53	0.0019	00:00[a]
					HNO	00:15	10.36	00:15
					P mean	00:54	0.0023	-
					P std	27	0.0010	-
					P rsd	50	42	-
					HNO mean	00:16	10.24	00:14
					HNO std	0.55	0.1386	1.0
					HNO rsd	3.51	1.354	7.1
VX	0.0163	Exhaust	22.0	50.3	Phosphorus	00:28	0.0031	00:20
	0.0181	Exhaust	22.0	50.3	Phosphorus	00:31	0.0039	00:22
	0.0189	Exhaust	22.0	50.3	Phosphorus	00:36	0.0041	00:32
	0.0192	Exhaust	22.0	50.3	Phosphorus	00:29	0.0044	00:31
	0.0190	Exhaust	22.0	50.3	Phosphorus	00:23	0.0043	00:36
					mean	00:29	0.0040	00:28
					std	4.7	0.00052	6.9
					rsd	16	13	24

Table C.21 – Hot/Cold Start Tests

Chemical	Challenge Concentration (mg/m^3)	Temp (°C)	RH (%)	Startup Delay Time (mm:ss)	Alarm? (Y/N)	Time to Alarm	Reported Concentration (mg/m^3)	Recovery Time
DELAY TIMES NO AGENT PRESENT		22.1	11.7	00:49				
		22.0	22.5	00:42				
		22.1	23.0	00:48				
		22.1	25.8	00:43				
		22.1	26.1	00:43				
HOT START NO AGENT PRESENT		37.8	36.0	01:38				
		39.5	39.4	01:51				
		39.5	52.7	01:51				
		39.1	47.6	01:50				
		42.4	37.9	01:59				
CK	50.0	22.9	50.6		HNO	00:25	7.86	00:09
CK	50.0	23.0	50.7		HNO	00:16	10.04	00:10
CK	50.0	23.1	51.2		HNO	00:16	9.81	00:09
CK	50.0	23.1	51.3		HNO	00:17	9.87	00:10
CK	50.0	23.1	51.3		HNO	00:15	9.92	00:10
COLD START NO AGENT PRESENT		6.9	38.8	02:44				
		6.0	30.9	03:04				
		6.5	21.7	03:06				
		5.3	47.1	03:13				
		6.5	24.3	03:04				
CK	50	22.6	49.0		HNO	00:16	10.15	00:13
CK	50	22.6	49.8		HNO	00:14	9.83	00:11
CK	50	22.7	50.3		HNO	00:16	10.03	00:08
CK	50	22.7	49.6		HNO	00:15	10.80	00:09
CK	50	22.8	49.4		HNO	00:15	10.80	00:10

Table C.22 – Battery Life Tests

After start up time of 30 seconds, detector was challenged with subsequent challenges of 50 mg/m^3 of CK

Elapsed Time (hh:mm:ss)	Temp (°C)	RH (%)	Alarm? (Y/N)	Time to Alarm (mm:ss)	Reported Concentration (mg/m^3)	Recovery Time (mm:ss)
0:05:30	22.0	49.1	Y	00:09	2 lights	00:16
0:40:30	22.2	50.3	Y	00:10	2 lights	00:14
1:15:30	22.1	50.9	Y	00:10	2 lights	00:14
1:50:30	22.1	50.5	Y	00:10	2 lights	00:15
2:25:30	22.1	50.5	Y	00:10	2 lights	00:15
3:00:30	22.2	50.4	Y	00:10	2 lights	00:16
3:35:30	22.2	50.8	Y	00:10	2 lights	00:14
4:10:30	22.2	50.4	Y	00:10	2 lights	00:16
4:45:30	22.2	50.7	Y	00:09	2 lights	00:13
5:20:30	22.2	50.3	Y	00:10	2 lights	00:14
5:55:30	22.3	50.3	Y	00:10	2 lights	00:16
6:30:30	22.3	50.2	Y	00:10	2 lights	00:14
7:05:30	22.3	50.2	Y	00:10	2 lights	00:15
7:40:30	22.3	50.2	Y	00:10	2 lights	00:15
8:15:30	22.2	50.2	Y	00:09	2 lights	00:13
8:50:30	22.3	50.2	Y	00:09	2 lights	00:15
9:25:30	22.2	50.2	Y	00:10	2 lights	00:15
10:00:30	22.2	50.2	Y	00:10	2 lights	00:14
10:35:30	22.2	50.1	Y	00:10	2 lights	00:15
11:10:30	22.2	50.0	Y	00:10	2 lights	00:15
11:45:30	22.2	50.0	Y	00:10	2 lights	00:16
12:20:30	22.2	49.9	Y	00:10	2 lights	00:14
12:55:30	22.2	49.9	Y	00:11	2 lights	00:15
13:30:30	22.2	49.8	Y	00:10	2 lights	00:15

14:05:30	22.2	49.7	Y	00:10	2 lights	00:15